CHAPTER 3

MATERIALS AND METHODS

In this chapter, the details of study area, status of marine fisheries of Gujarat, rationales of satellite data selection for fisheries application, observational requirement and capabilities of satellite sensors, data utilized in the study and analysis procedure for the retrieval of chlorophyll concentration and SST using satellite data, methodology for generating PFZs *and fish catch analysis have been discussed. The step by step procedure followed for analysis of satellite data, fish catch data, image interpretation for identification of* PFZs *and interpretation of fishing operations data have been discussed in this chapter.*

List of tables in the Chapter 3

List of figures in Chapter 3

Plates in Chapter 3

CHAPTER 3 – MATERIALS AND METHODS

3.1. Study area

3.1.1. General description of Study area

The study area is Off Gujarat Coast, North West Coast of India in the Northern Arabian Sea. Gujarat State has highest coastal line of about 1600 km among the maritime states of India, which is about 19.7% of the total coast line of the country. Figure 3.1 indicate the study area along with depth contours in meters. The continental shelf area along the state (Latitude 20° N to 23° N) is about 1,64,000 Sq. Km. i.e. highest continental shelf areas along the Indian coastal line (about 32.54% of total country's continental shelf). The maximum width of the continental shelf is about 190 nautical mile and minimum is 55 nautical miles. The gradient of the shelf area is 1:1.769 at maximum width point and 1:1.537 at the minimum width point. The shelf area is wider and vast, therefore fishing grounds are extensive. The exclusive economic zone (EEZ) of Gujarat coast is estimated at 2,14,060 km^2, which forms 10.59% of Indian EEZ. The detail comparison of basic marine fisheries related parameters of study area with India are given in Table 3.1. The region has a high rate of primary production, attributed to Narmada discharge in Gulf of Cambey. The areas is affected by powerful Somalia current which grazes Saurastra coast in a clock wise manner during south west monsoon and off-shore wind off the Kathiawar peninsula during northeast monsoon induce the primary production, which support the ecosystem to sustain.

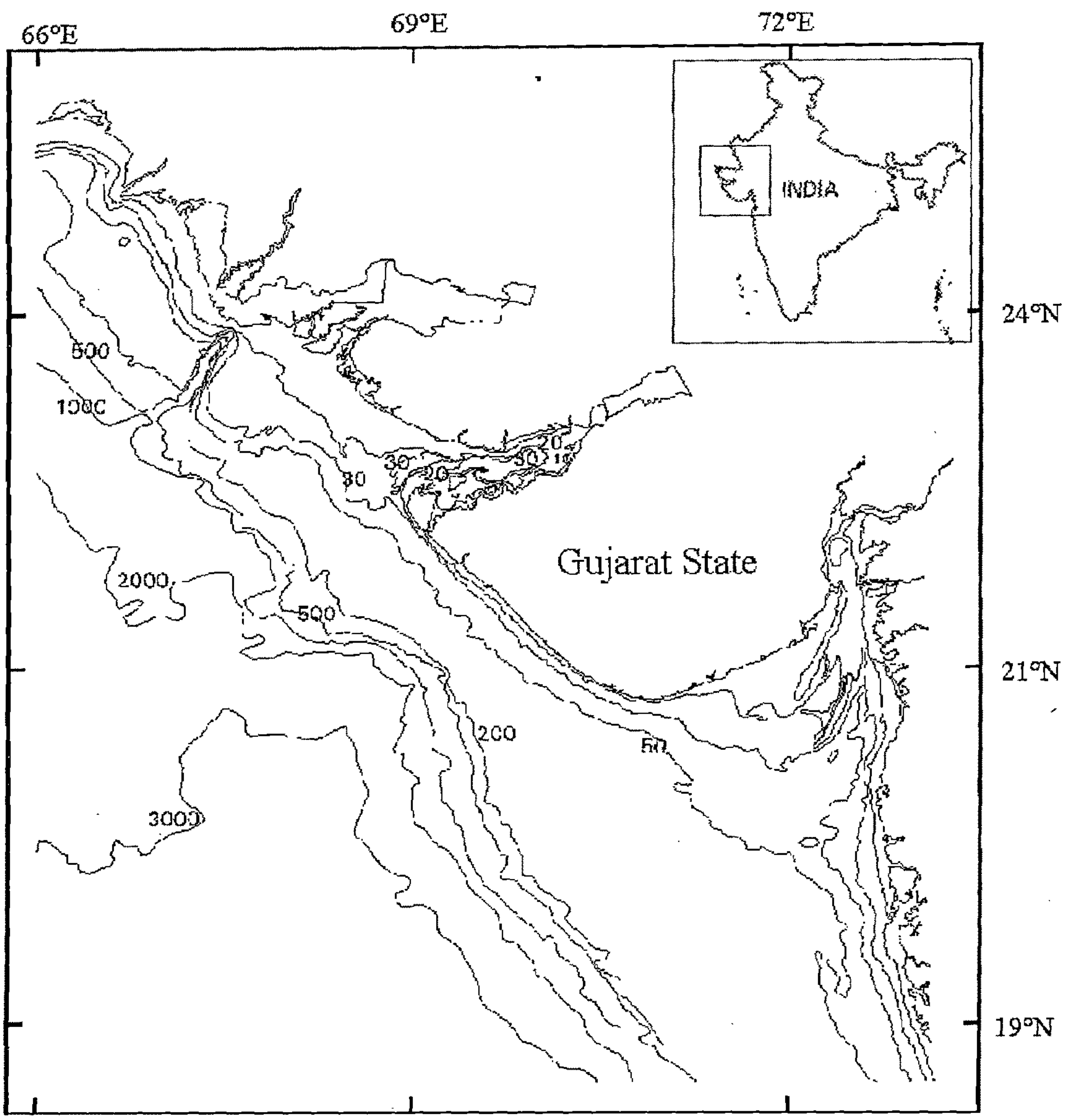

Figure 3.1.: Map showing the study area off Gujarat Coast, North West Coast of India, Northern Arabian Sea. Depth contours are in meters.

Table 3.1. Details of parameters related to marine fisheries off Gujarat coast

Parameter	Units	Gujarat	India	Gujarat's Share (%)
Coastline	Km	1600	8041	19.9
Continental shelf	$x10^5 Km^2$	1.64	5.06	32.41
Exclusive Economic Zone	$x10^5 Km^2$	2.14	20.20	10.59
Total fishermen (1997)	$x10^5$ No.	4.49	67.30	6.67
Total active fishermen	$x10^5$ No	1.57	24.85	6.62
Total fish landing centres	No.	881	3937	22.38
Marine fishery potential	$x10^5$ t	7.03	39.00	18.03
Total fishing fleets (1999)	No.	25985	280490	9.16
Mechanised boats (1999)	No.	11372	53684	21.18

3.1.2 Hydrography of study area

The offshore temperature range from 22° to 25° C in January-February to about 27° - 29° C in May and June with secondary minimum in August as a consequence of southwest monsoon, more or less marked secondary maximum is observed in November (means from monthly charts by Wooster et al., (1967). Wyrtki's (1971) bi-monthly charts show the mixed layer as being deeper than 80m in January/February, it become shallower than 40m in the western part of the area during March/April, and above 40m every where from July through November/December. Accordingly, the maximum temperature gradient jumps from a depth of about 120m in February to about 25m in May to August, deepen to less than 50m in September/October and stays about 40m in November/December.

This shallow gradient results in the open sea largely from the formation of seasonal thermocline. The bathythermograph observations (Banse, 1973) suggest that the seasonal warming reduces the depth of mixed layer drastically already in March/April. Also there is seasonal rise of the 20° N isotherm, as well as of the isotherm s above 23° N which near-shore leads to upsloping of cold water. This upsloping persist after the SouthWest monsoon has sensed, this effect the surface temperature and primary production far into the open sea (Banse, 1968). The surface salinity of Northern Arabian Sea ranges from 36.2 to 36.5 ‰. The usual salinity maximum of Tropical Ocean, in the top of the thermocline, seems here to be formed in the middle of northern Arabian Sea. Banse (1968) mentioned the complicated average current trend in the area during November, the month of transition from the clockwise (summer) to anti-clockwise (winter) pattern. Further, for the shelf of Saurashtra and Bombay area during spring, Banse (1973 shown that a long, narrow trough of the thermocline is a regular feature, which cannot be reconciled with the rotation of a simple clockwise current near and above the shelf during this season. In addition, there is transit variability within season. Düing's (1970) charts of dynamic height show large cyclonic and anti-cyclonic eddies which presumably move horizontally, North of 20° N, though his coverage was inadequate except for March/April. Das et al (1980) also showed similar feature for February/April in this area. The concentration of dissolved oxygen content decline rapidly, with increasing depth. Values at 100m is commonly below 1 ml/l (Wyrtki, 1971). These low concentrations form the top of the huge minimum layer at intermediate depths in which values below 0.2 ml/l occur north of 15° N throughout. In the Northern Eastern part of the seas, concentrations even decline to below 0.05ml/l, and reduction of nitrate take place in mid-water (Qasim, 1982).

3.1.3. Status of Marine fisheries of Gujarat

Marine fishing industry of Gujarat has over 28,000 fishing vessels, of which 65% are mechanized. About 37% of the total mechanized fishing fleets are trawlers intensively exploiting the inshore and offshore waters up to 90m-depth contour. Table 3.2 indicates the details of different types of fishing vessels operated along Gujarat Coast during 2000-2001.

Table 3.2. Details of fishing fleet of Gujarat (2000-01)

Category of Fishing Craft	No.	%
Mechanized trawlers	6948	24.20
Mechanized gill netters	3375	11.76
FRP gill netters	5162	17.98
Motorized wooden gill netters	1813	06.32
Bag netters	1238	04.31
Others	10170	35.43
Total	28706	100.00

The major part of fish production is obtained by the operation of trawls, gill nets and dol nets. The fishery resources can broadly classified into four main groups – pelagic, column, and demersal. Gujarat exported 1,24,159 t of marine products, valued at Rs. 6150 million during 2000-01. Various elasmobranches, bony fishes, cephalopods and crustaceans represent major fish catch.

The fishery resources survey off the North-West coast of India dates back to the investigations of *S.T. William Garrick* (1902) in the then Bombay Presidency. This was followed by *M.T. Pratap* and *M.T. Ashok* (1949), *MF.V. Jyoti* and *M.F.V. Tapasi* (1950-51) and the commercial fisheries operations from onboard *M.V. Taiyo Maru* (1951- 1954). Since then the survey operations have been going on through the exploratory vessels of Government of India by Fishery Survey of India (FSI). The State Department of Fisheries initiated the demonstration of trawl fishing operations within 72 m depth, in year 1962, through its 14.5 m LOA stern trawler (*M.F.V. Gulf Shrimp, M.F.V. Indian Salmon* and *M.F.V. Silver promfret*). All these operations indicated the availability of sizable quantities of shrimp, eel, perch, jew fish, threadfin fish and cephalopods off Gujarat coast. This resulted in the establishment of trawl fishing along Gujarat Coast by early seventies. Subsequently, in 1977, a Polish stern trawler (*M.T. Muraena*) conducted exploratory fishing for pelagic, mid-water and demersal resources off Gujarat, up to 170 m depth contour. Thereafter, during 1979-80, Fishery Survey of India deployed the 40.5 LOA *Matsya Nireekshini,* along with *Matsya Vershini*, for exploratory fishing, up to 300 m depth contour, off the Gujarat Coast. Based on the surveys conducted by the Fishery Suvery of India and other agencies, Somvanshi (2001) assessed the maximum sustainable yield off the northwest and Gujarat Coast as given in Table 3.3.

Table 3.3. Maximum sustainable yeild estimates off north-west coast of India (Somvanshi, 2001)

Region/Area	Resources	Resources Potential (x10^5 t)
North West coast	Mid water	5.20
	Demersal	6.90
	Total	12.10
Gujarat coast	Mid water	2.5
	Demersal	4.5
	Total	7.0

The Survey also revealed that the deep sea demersal stocks are supported by less number of species. However, these are available in abundant quantities. The important groups supporting the stock are threadfin, skates, catfish, bombay duct etc. The mid-water stocks are supported by the horse mackerel, scads, ribbon fishes, little tuna, squids and myctophids. These species are reported to sustain the fishery in a significant way. The fishing ground off Kutch and Saurashtra were the prime attraction during winter months.

3.1.4. Marine fish production of Gujarat

The marine fish production trend in Gujarat is summarized in Table 3.4. In general, fishing season is from September – May. The season starts from September and gradually reaches a peak in winter. Thereafter, fishing operations and the catch declines gradually. By mid May, the sea becomes choppy and the fishing season comes to close. Normally there is no fishing operation in the monsoon throughout state, except the Gulf of Kutch.

Table-3.4. Marine Fish production during last five decades in Gujarat

Year	Fish Production (t)	Decennial growth (%)
1960-61	79412	-
1970-71	151000	90.36
1980-81	218000	44.77
1990-91	500462	128.66
2000-01	620474	23.98

The estimates of month wise fish landing and its percentage share in annual marine catch in Gujarat, during the past few years are given in Table 3.5. With the initiation of commercial trawling in the waters off Gujarat, the state established a niche for itself among the marine fish producing states in India. The advancement made by the state in this sector is evident from the fact that its marine fish production increased from less than 0.1 million t in 1971 to 0.7 million t in 2000. The variation in percentage contribution of different resources to the total fish catch clearly identifies the resources which are on the declining side and those which hold promise for the future.

Table-3.5. Total Marine fish production in Gujarat during last four decades.

Species Group	1960-61	1970-71	1980-81	1990-91	2000-01
White Pomfret	3413 (04.30)	6199 (04.10)	9539 (04.36)	10694 (02.14)	9169 (01.48)
Black Pomfret	1699 (02.14)	4432 (02.93)	3248 (1.48)	2141 (00.43)	2567 (00.41)
Bombay Duck	23320 (29.37)	48411 (32.02)	36270 (16.57)	72712 (14.53)	86085 (13.87)
Croakers	4657 (05.86)	5054 (03.34)	59999 (27.41)	184851 (36.94)	197006 (31.75)
Shrimps	2337 (02.94)	9532 (06.30)	8550 (03.90)	10724 (02.31)	9013 (08.70)
Cephalopds	00.00 (00.00)	00.00 (00.00)	5182 (02.37)	12380 (02.47)	22857 (03.68)
Jewfish	13397 (16.87)	10630 (07.03)	5848 (02.67)	13010 (02.60)	8814 (01.47)
Elasmobra-nchs	1790 (02.25)	5891 (03.90)	6306 (02.88)	9580 (01.99)	14079 (02.27)
Clupeids	6909 (08.70)	5909 (03.91)	5518 (02.52)	7773 (01.55)	11186 (01.82)
Golden anchovy	3736 (04.70)	3029 (02.00)	7631 (03.49)	16648 (03.33)	2694 (00.43)
Perches	00.00 (00.00)	00.00 (00.00)	560 (00.26)	3805 (00.76)	6942 (01.12)
Seerfishes	00.00 (00.00)	00.00 (00.00)	4169 (01.90)	6331 (01.27)	7706 (01.24)
Threadfins	00.00 (00.00)	00.00 (00.00)	203 (00.09)	2328 (00.47)	2079 (00.34)
Catfishes	946 (01.19)	2093 (01.38)	6625 (03.03)	12435 (02.48)	19568 (03.15)
Ribbonfishes	00.00 (00.00)	00.00 (00.00)	4104 (01.88)	40906 (08.17)	38429 (06.19
Total Marine Fish Production	79412	151190	218872	500462	620474

(Figures in parenthesis indicate percentage contribution.)

3.2. Selection of satellite data

Selection of satellite data for fisheries application is based on the time and space scales of (i). important fisheries related parameters, (ii). oceanographic events/ oceanographic process relevant to fisheries resources distribution, and (iii). life cycle of fishery resources and their recruitment. Hence, selection of satellite data is based on observational requirement and capabilities of satellite sensor for fisheries resources exploration should be considered.

3.2.1. Time, Space and Fish Scale – a biological perspective

Biologists often tend to ignore time and space scales when they design field programs established to support fishery management. In many cases there is a mismatch between the time and space scales addressed by the field research programs and those utilized for the development of the retrospective models that are used to manage the studied populations.

Time Scales -

Biological processes naturally occur over a wide range of time scales, from behavioral responses to individual storms to extinctions caused by factors operating on geological time scales. For the purposes of fisheries it has been classified time into four usable categories; weather, seasonal, inter-annual and regime scales (Table 3.6 A). From a marine fisheries perspective, weather scale effects are primarily storm related and wind is the most important factor, although flooding may be a major factor for marine species with estuarine life history stages. Events at this scale have generally limited affects on adult marine fishes and are primarily associated with behavioral responses and microscale distribution changes. However, storms can have a major effect on early life history stages and in fact a major fishery paradigm is based on factors which occur at this time scale. Seasonal scale environmental effects that are effects, which occur over a several month period (i.e., a spawning season) are of major concern in many fisheries. The environmental factors operating at this time scale are quite broad and include transport, upwelling of nutrients, spawning season temperatures, winter turbulent mixing, and spring blooms. Biological responses at this time scale include growth, distribution, and development of energy reserves, reproductive output and reproductive success. There has been a heavy reliance on environmental data at this scale for retrospective studies. Inter-annual environmental factors have biological responses similar to most of those associated with the seasonal time scale listed above. The principal difference between environmental factors at these two scales is that factors at the seasonal scale may be the result of environmental variations at the more local, intermediate spatial scales, whereas environmental variations at the annual scale, for example El Niño phenomena, are more likely to be the result of environmental process operating at the larger space scales. Regime scale environmental factors are, almost by definition, associated with large-scale shifts in oceanic circulation, upwelling, and vertical mixing. At this time scale it may be difficult to separate abiotic environmental process, biotic environmental processes, density-dependent processes and overexploitation effects; however, this time scale is the one most often associated with the failures of marine fishery management.

Space Scales -

For the purposes of present study spatial scales have been divided into four usable categories; micro, meso, regional and basin scales (Table 3.6. B). It should also be noted that the temporal and spatial scales are assumed to be linked (i.e., storms are associated with micro and meso spatial scales and El Niño events are associated with regional and basin spatial scales). This does not necessarily imply that events which occur at other scale combinations (i.e., a mid-Atlantic strike of a large meteor; micro-scale temporal and basin scale spatial scales), are unimportant, only that they are largely outside of the realm of fishery research and management. Large fisheries field programs have been designed to sample on a broad range of spatial scales and these scales were heavily influenced by the fishery paradigms in vogue when the programs were started. Older programs such as the CalCOFI Program of the Southwest Fisheries Science Center and the Resource Assessment and Conservation Engineering trawl surveys of the former Northwest and Alaska Fisheries Center were designed to cover the distribution of wide-ranging stocks and they are therefore regional in spatial coverage. Others such as the North Pacific Albacore program were designed as basin scale programs due to the even larger stock area occupied by albacore. More recent field programs such as the Shelikof Strait (FOCI) and Georges Bank (GLOBEC) programs have focused on meso or sub-regional spatial and the smaller temporal scales in response to early life history paradigms (i.e., as in "critical early life history stages").

Fish Scales -

Although it is seldom mentioned, it is just as important to know the scales at which fish populations interact with their environment as it is to know the scale at which abiotic oceanic processes occur. The emphasis on fish populations rather than fish is critical as fishery management is based on the population response not on the individual response. For example, a large scale warm anomaly could be viewed as negative for individuals at the lower latitude edge of a stocks range and positive for individuals at the high latitude edge. Very precise, smaller scale process oriented studies in the two locations would, in this case, be expected to give opposite results to the same environmental forcing. Fishes have evolved a wide range of life history characteristics which allow their populations to minimize the adverse effects of environmental variability at various time and space scales. These include differing longevity, age at maturity, fecundity, body size, mobility, and even large differences in the size of the geographic area that they occupy (Table 3.6.C).

Table 3.6 Time, Space and Fish scales to be considered for observations from space

3.6.A TIME SCALES

Sr. No.	**Type**	**Period**	**Environmental Factor**	**Biological Processes**
1.	Weather	1-5 days	Storm, Floods.	Behavior, Distribution, Early life history effects
2.	Seasonal	2-3 months	Winter turbulent mixing, Offshore transport, Spawning season temperature, Spring bloom.	Growth, Energy reserves, Reproductive output, Larval drift, Reproductive success
3.	Inter-annual	1-2 years	El Niño phenomenon	Growth, Recruitment, Distribution
4.	Regime	5-30 years	Shifts in oceanic circulation, Fleet development	Carrying capacity changes, Overexploitation effects
5.	Geological	100+ years	Erosion and sedimentation, Sea level changes, Plate movement.	Extinction and evolution

3.6.B. SPACE SCALES

Sr. No.	**Type**	**Scale**	**Fishery Research Programs**
1.	Microscale	0.001-1 km.	SPACC (GLOBEC Program)
2.	Mesoscale	5-200 km	Georges Bank GLOBEC Program, FOCI, Tiburon Rockfish Surveys
3.	Regional	500-2000 km	CalCOFI Program, RACE trawl surveys, Most fishery population analyses (by default)
4.	Basin scale	5000-20000 km	SWFSC Albacore Program (by default), Regime Group (larger than individual stocks)
5.	Global	The whole globe	The World's fishery

Continued table 3.6...

3.6.C FISH SCALES

Sr. No.	Species	Age at Maturi -ty (yr)	Multiple Spawner	Maxim -um Age (yr)	Maxim -um Size (cm)	Annual Move- ment (km)	Stock Area (km)
1.	Anchovy	1-2	Yes	7	22	400	600
2.	Herring	2-3	No	9	40	300?	400
3.	Sardine	1-3	Yes	14	34	2000	2500
4.	Mackerel	1-2	Yes	11	64	2500	3000
5.	Albacore	5-7	Yes	15?	150	7000	9000
6.	Bocaccio	3-6	No	40	92	100?	1000
7.	Splitnose	6-9	No	80	40	100?	1000

Some clupeid stocks spawn a single batch of eggs per year at a single site at essentially the same time each year. (i.e., Pacific herring, Clupea pallasi), others spawn 40 batches per year at a multitude of sites (i.e., South African sardine, Sardinops sagax ocellata) Some species mature at a young age, can fully develop and spawn a batch of eggs in just 24 hours, or two batches in 48 hours, and often move thousands of kilometers in a matter of months (i.e., Pacific mackerel, Scomber japonicus). Others have a delayed age at maturity, are viviparous, take several months from insemination to extrusion of larvae and they may move less than a kilometer in 50 years (i.e., splitnose rockfish, Sebastes diploproa). In quite different ways both Pacific mackerel and splitnose rockfish have life history characteristics which largely buffer their populations from environmental variation at the smaller scales (Table 3.6). In contrast, the Pacific herring is likely to be affected by environmental events at the smaller time and Space scales as well as those at the larger scales.

3.2.2. Description of observational requirement and capabilities - remote sensing perspective

Factors such as rapid population growth, expanding use and abuse of the oceans and increasing awareness of environmental changes have produced a sense of urgency to understand and minimize human impact on the oceans and atmosphere. It should be emphasized that virtually all important environmental problems require interdisciplinary approaches and necessarily atmospheric, physical, chemical, biological, optical, acoustical and geological data sets. Ideally, these data should be collected simultaneously, synoptically and time and space scales to observe the processes of interest, (Dickey, 1991), (figure 3.2). Detection limits, precision and accuracy of ocean measurements are important. However, the oceans are naturally dynamic, with large amplitude periodic and episodic variability, which is especially confounding for quantifying long-term trends and changes. The time space diagram is shown in figure 3.3 provides rough means of estimating the utility of different platforms in space (horizontal aspect depicted in the figure) and time. It also reemphasizes the need for deploying sensors from both in-situ and remote platforms. Nesting of platform can optimize the use of these observational assets. Figure 3.4 indicate the rough scales of doubling of particular groups of organisms versus size with organism sampling capabilities of various technologies (Sheldon *et al.*, 1972). This figure indicates the rate of doubling and according the observation system required for the organism exploration. These clues of the remote sensing system required with different types of resolution like spatial, temporal and type of data acquisition system required.

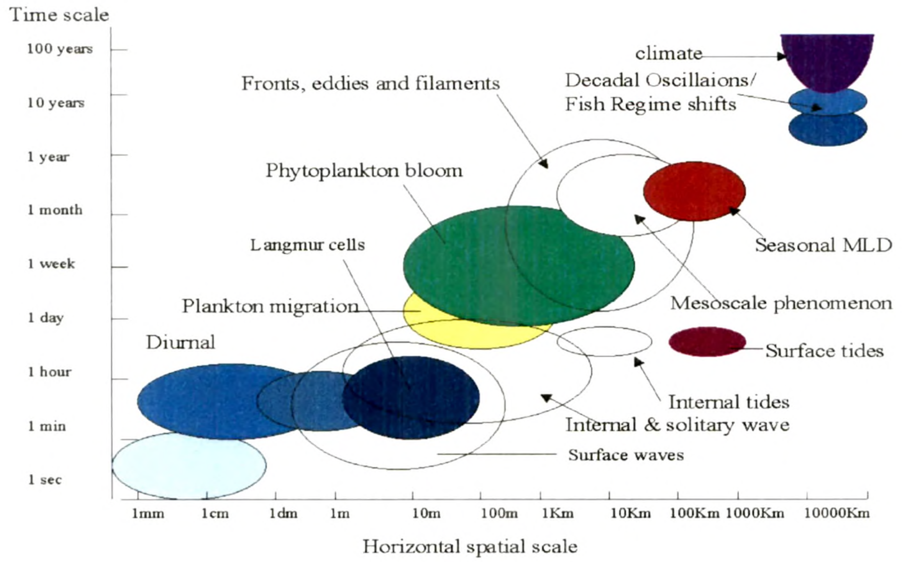

Figure 3.2: Time and horizontal space scales of some of the important oceanic processes.

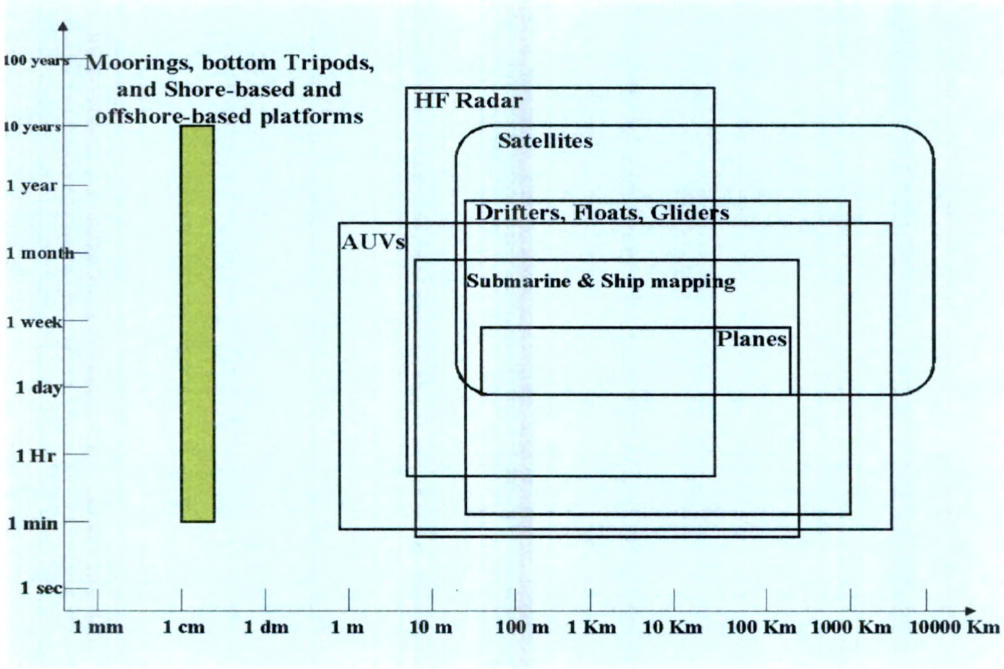

Figure 3.3: Time and horizontal space domains accessible with different observing platform

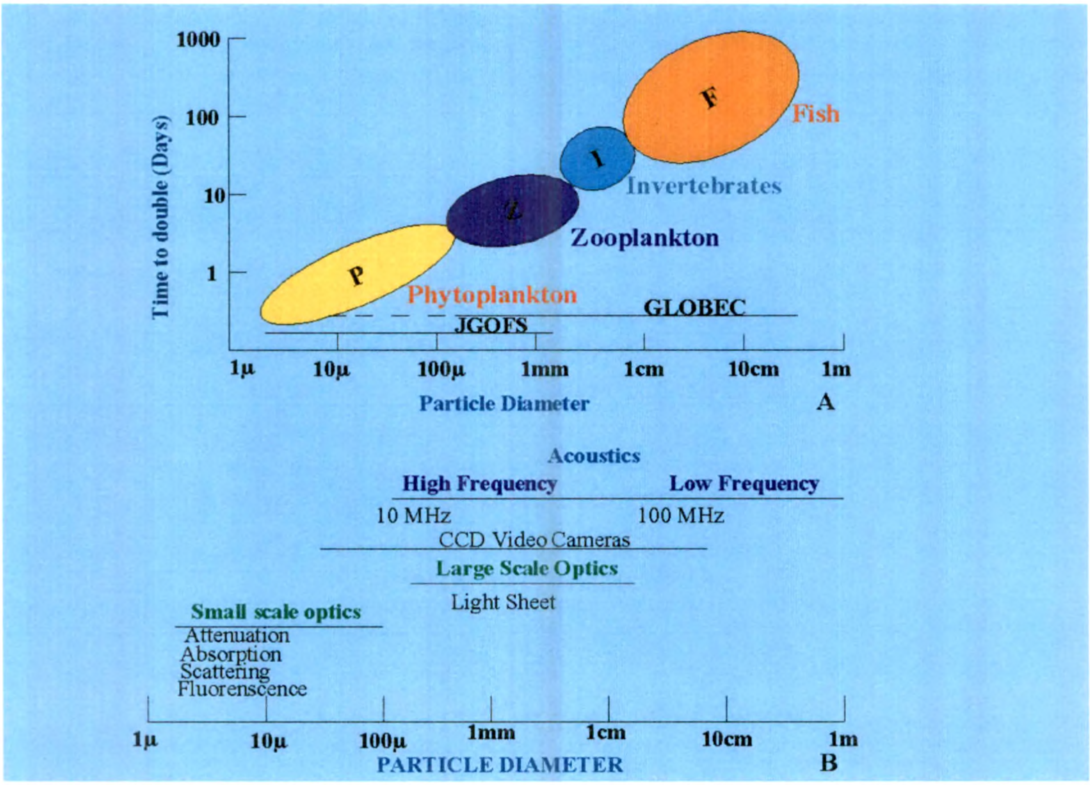

Figure 3.4: A. Rough scale of doubling of particular organisms versus size. B. Organism sampling capability of various technologies.

There are three main classes of satellite sensor systems being used currently for oceanography. They are (1) passive systems sensing in visible to thermal infra red portion of electromagnetic spectrum, (2) passive microwave systems sensing in emitted microwave radiation and (3) active microwave systems which provide their own illumination and measure the properties of scattered returned from the ocean surface. In this study passive satellite sensors in visible and thermal infrared data have been used. This data fulfill the requirement of data for retrieval of two important parameters i.e. chlorophyll concentration and SST which can be linked to fishery resources distribution. Ocean Colour Monitor data provide ocean colour information based on the backscattered radiation of oceanic constitutions like phytoplankton, sediments, yellow substance etc. The technical component of scientific and operational satellite ocean colour mission include, (i). sensor with appropriate specifications including the number and placement of spectral bands, signal to noise performance and footprint/swath characteristics to meet coverage requirements, (ii). calibration programs to ensure sensor stability (iii). appropriate algorithm to calculate the data product of interest to scientist, (iv). validation programs to demonstrate that the data product, (v). mechanism for timely delivery of data product to users. Minimum requirements for ocean colour measurements in the open ocean include mainly spatial and temporal requirement, spectral requirement and radiometric requirements. Spatial and temporal resolution requirement for the scales drive ocean colour sensors at which biological processes operate in the ocean as well as practical constraints. Spectral resolution requirements derive from the need effectively to remove atmospheric components of the total signal acquired by satellite as well as the need to compute an accurate representation of biological products, primarily chlorophyll, from the spectral radiance emanating from the ocean. For this, absorption and back scattering properties of chlorophyll pigment and absorption as well as scattering properties of aerosol should be considered. Oceanic signals are vary low; they contribute ~10% of total signal so high signal to noise ratio is required. High radiometric resolution required so as accommodating the wide range of signal. The information derived from ocean colour sensor is chlorophyll concentration over large area which representing the phytoplankton concentration i.e. first component in marine food chain. Chlorophyll concentration is considered as an index of biomass availability in the marine food web. This information represents the availability of food resources to fishery resources. The thermal sensor should be with at least two spectral channels in thermal region, so as to calculate the attenuation of signal due to atmospheric absorption. Temperature is an important physical parameter that control bio-chemical processes and distribution of marine resources. This is also an indicator of circulation pattern. Sea surface temperature is an indicator of suitable environment to fishery resources. Hence, remotely sensed chlorophyll concentration and sea surface temperature (SST) can explain the suitability of environment and availability of food resources which can be utilized for fishery resources exploration. Microwave data for retrieval of SST were not used because of its coarse resolution and poor retrieval accuracy.

Most fisheries and protected species application of satellite remote sensing have made use of visible and thermal infrared satellite data for measurement oceanic constituents and temperature, respectively. Data selection is based on the parameters, which are important for fish distribution and can, derived easily from satellite sensors. Most fisheries applications of satellite remote sensing use AVHRR infrared thermal and optical data like, Sea WiFS, OCM, and MODIS to retrieve Sea Surface temperature (SST) and ocean color, respectively. This can be the case primarily because these data (a) have been readily available, (b) after conversion to SST and chlorophyll concentration or related optical, the derived measurements can be used directly in marine resources applications i.e. these parameters are most relevant for fish distribution, (c). there is general understanding and confidence in the meaning of satellite derived data. Apart form these microwave data from SeaWinds on board Quik SCAT is being utilized for deriving wind speed and direction to understand the mass transport and its impact on resources and phytoplankton as well as larval transport.

3.2.3. Capability of Satellite Sensors

Limitation of SST - The **infrared sensor** can detect radiation emitted from the sea surface only, hence it provide only surface information. In many occasions it is affected by evaporation, diurnal warming, summer insolation etc. This is the limitation of thermal sensor for detecting features of weak gradient on images. But it is not redundant because, certain event like upwelling, signatures of nutrient rich cool water will appear first in the thermal imagery. Such events will be seen in ocean colour images after initiation of the primary production.

Advantages of ocean color -

The ocean color sensor has look into capability, i.e. the ability to visualize the marine structure originated from down to one-attenuation depth. Hence, the color sensor can distinguish the water masses based on the different column production, which is hardly differentiated by the skin property in IR region. This overcomes the deficiency of the feature detection through SST gradients.

Limitation of Satellite data for fisheries -

The primary disadvantages are that satellite measurements are mostly limited to very near surface film to subsurface of the ocean in optical and thermal infrared measurements. Also these measurements are restricted to cloud free areas. In many ocean regions, conditions at the surface have been found to be representative of those in the upper 100-250 m (Godfrey and Ridgeway, 1985). Although SST measurements can be representative of the upper mixed layer (Maul et al. 1984) many important species live below the thermo cline or on the bottom, where temperature patterns are not necessarily apparent at the surface. The cloudiness problem is at least partially overcome by combining infrared and visual images of the same area acquired over several days, resulting in a temporally averaged in image, which oftentimes contains extensive cloud free areas. The above discussions clearly indicate the frequency of data and scale required for fisheries study. Ocean color and temperature variables can be easily retrieve from the present sensors. These two parameters can be easily obtained using optical and thermal infrared sensors data.

3.3 Satellite data used

Chlorophyll concentrations in oceanic water mass represent the primary production, which is first link in the food chain and considered as an indicator of fishery resources accumulation. This parameter can be derived using ocean color sensors. Coastal Zone Color Scanner (CZCS) was first sensor on board Nimbus satellite. Similar advance sensors are operationally provides data for ocean color studies. Two types of the satellite sensor data have been used in this study. They are optical and thermal sensor data.

3.3.1. Optical sensors for sensing ocean color

These sensors basically designed for estimating the constituents of oceanic water like chlorophyll concentration, suspended sediments, yellow substance etc. In general they have capabilities to sense in narrow spectral band in visible and near infrared region of electromagnetic spectrum. Ocean Color Monitor (OCM) data have been used for retrieval of chlorophyll concentration in this study. On May 26, 1999 Indian Space Research Organization (ISRO) launched the IRS-P4 satellite, carrying two oceanographic payloads i.e. Ocean Color Monitor (OCM) and Microwave Scanning Multi-frequency Radiometer (MSMR). Salient features of IRS-P4 are given in table 3.7. OCM is a solid state camera operating in eight narrow spectral bands. The first payload Ocean Color Monitor (OCM) is designed to measure ocean color, the spectral variation of water leaving radiance that can be related to concentration of phytoplankton pigments, suspended matter and colored dissolved organic matter in coastal and oceanic waters, and the characterization of atmospheric aerosols. The central wavelengths, the bandwidths and the other technical specifications of OCM sensor are given in Table 3.8.

Table 3.7. Description of salient features of IRS P4 satellite

Sr. No	Salient features	Description
1.	Orbit Polar	Sun synchronous
2.	Altitude	720 km
3.	Inclination	98.28 degree
4.	Local time of Eq.crossing	12 noon
5.	Repetitivity cycle	2 days
6.	Size	2.8m x 1.98m x 2.57m
7.	Mass at lift off	1050 kg
8.	Length when fully deployed	11.67 m
9	Attitude and Orbit Control	3-axix body-stabilized using Reaction Wheels
10.	Power generation	Magnetic Torquers and Hydrazine Thrusters Power, 9.6 Sq.m Solar Array generating 750w, Two 21 Ah Ni-Cd Batteries
11.	Mission Life	5 years

3.3.2. Thermal sensors for sensing temperature

Sea surface temperature is an indicator of suitable oceanic environment for fish distribution. Distributions of some species are depends upon the temperature range. NOAA series of satellites are being operationally utilized to delineate the oceanic features for fisheries. The details of sensor parameter are given in Table 3.8. Apart from this MODIS Tera also provide SST products. They are design to detect the emitting radiance in the thermal region of electromagnetic spectrum. These sensors have broad band and poor spatial resolution so as to detect weak emitted signals of oceanic water. The details of the sensor parameters are given in Table 3.8.

Table 3.8: Technical characteristics of OCM and NOAA AVHRR payload

Parameter	OCM	**NOAA AVHRR**
Swath	1420 Km	2400 Km
Equatorial crossing time	12 noon	0730 & 1430 hrs
Spectral Range	404-882 nm	0.58 – 12.5 μm
Quantisation	12 bits	10 bits
No. of Channels	8	5
Wavelengths	Channel 1: 404-423 nm Channel 2: 431-451 nm Channel 3: 475-495 nm Channel 4: 501-520 nm Channel 5: 547-565 nm Channel 6 :660-677 nm Channel 7: 749-787 nm Channel 8: 847-882 nm	***hannel 1: 0.58-0.6μm*** ***hannel 2: 0.72-1.1 μm*** hannel 3: 3.55-3.93 μm hannel 4: 10.3 – 11.3 μm hannel 5: 11.5 - 12.5 μm
Spatial Resolution	1.1 Km	1.1 KM
Reetivity	2 days	daily
Equatorial crossing time	12 noon	0730 and 1430 hrs
Quantisation	12 bits	12 bits

3.4. Fish catch data used

Fishery Survey of India is nodal agency to survey fishery resources in Indian EEZ (Exclusive Economic Zone). They conduct regular survey through direct fishing using different type of fishing gears. The fish catch data were collected from the log book of FSI. Two fishing vessels namely, *Matsya Neerikshani* and *Matsya Mohini* were regularly operated in this study area. They operate trawl nets for fishing. Three fishing seasons (October – March) i.e. 1999 – 2000, 2000 – 2001, 2001 – 2002 were collected for the study. Other set of data was procured from Fisheries Department, Gujarat State. Fisheries Dept. catch data were belong to gill net and trawl net data. These data contain the geographic position of each track of fishing, fishing time per each haul, catch composition (species details), their weight in kg and some significant observations of the ocean like ocean color, wind direction speed, temperature etc.

3.5. Methodology

Methodology includes the analysis of satellite data to retrieve chlorophyll concentration and SST, interpretation of satellite derived chlorophyll concentration and SST images, delineation of oceanographic features, comparison of oceanographic features, interpretation of satellite derived products with in-situ fishing data. Fish catch data analysis includes computation of Catch per Unit Efforts (CPUE) and statistical analysis. Step by step procedure for satellite data analysis and fish catch data analysis is described here.

3.5.1. Satellite data analysis

Satellite data analysis was carried out using Silicon Graphics Image (SGI) processing system using Erdas Imagine software. Satellite data were procured from National Remote Sensing Agency (NRSA), Hyderabad. Satellite data analysis of optical and thermal data includes series of processing steps. They are required to be correct for atmospheric effects and geometric distortions before processing to compute derive chlorophyll concentration from optical data and sea surface temperature from thermal data. The retrieval of ocean colour parameters such as phytoplankton pigment (i.e. chlorophyll) and sea surface temperature (SST) from satellite data includes series of steps. The processing steps are shown in form of flow chart in Figure 3.5.

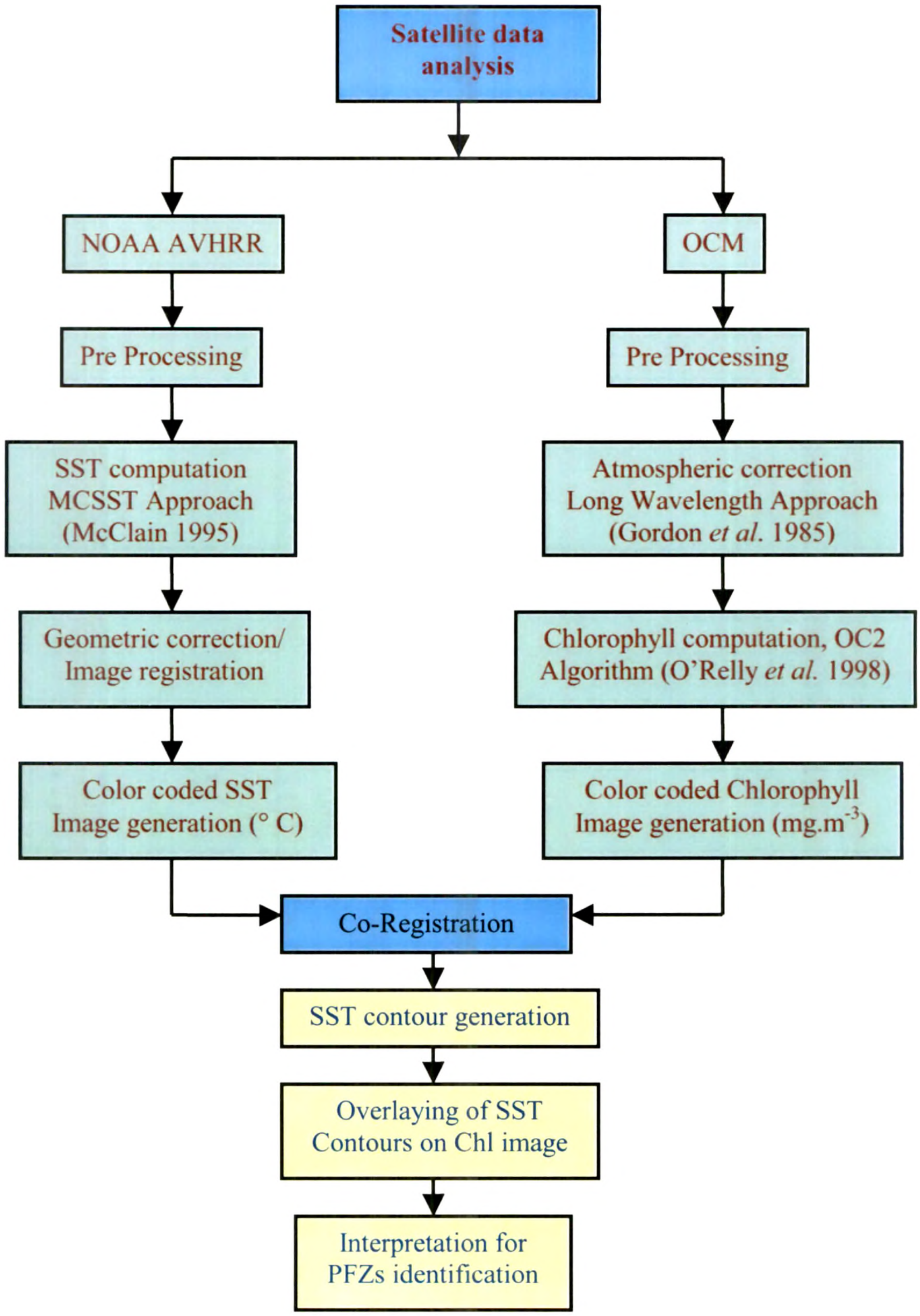

Figure 3.5: Schematic presentation of methodology adopted for data analysis

3.5.1.1. Analysis of OCM data

Pre-processing of IRS – P4 OCM data

The retrieval of ocean colour parameters such as phytoplankton pigment (i.e. chlorophyll concentration) and suspended matter in near shore waters involves two major steps. The first is known as atmospheric correction of visible channels to obtain normalised water leaving radiance and the second is application of bio-optical algorithm for water parameters retrieval. In oceanic remote sensing the radiance backscattered from the atmosphere and/or sea surface (specular reflection) is typically at least an order of magnitude larger than the desired radiance scattered out of the water, also known as water leaving radiance L_w. The process of retrieving L_w from the total radiance measured at the sensor L_t is usually referred as atmospheric correction. The ocean colour parameters such as chlorophyll concentration and suspended matter concentration are estimated from the retrieved spectral water leaving radiance by the application of suitable bio-optical algorithms.

Atmospheric Correction of IRS-P4 OCM Imagery

In case of oceanic remote sensing, the total signal received at the satellite altitude is dominated by radiance contribution through atmospheric scattering processes and only 8-10 % signal corresponds to oceanic reflectance. Therefore is become mandatory to correct for atmospheric effect, to retrieve any quantitative parameter from space. A long wavelength approach suggested by Gordon *et al.* (1980) and Mohan *et al* (1997) was adopted for atmospheric correction of optical data. It has been shown that for NIR channels the water leaving radiance coming out of ocean can be approximately put equal to zero (Gordon *et al. year)*. The top of the atmosphere (TOA) radiance in OCM channels 765 nm and 865 nm, mainly correspond to the contribution coming only from atmosphere, since water leaving radiance L_w(765 & 865 nm) can be safely assumed to be equal to zero. The Rayleigh scattering term (L_r) is computed using well-established theory. Once L_r is known then L_t is assumed equal to L_a, i.e. the aerosol path radiance. OCM payload has two channels at 765 and 865 nm in NIR region, a relationship is obtained for the spectral behaviour of the aerosol optical depth from these two bands. An exponential relationship for spectral behaviour of aerosol optical depth has been used for atmospheric correction algorithm. The aerosol optical thickness has been extrapolated to visible channels using this exponential relation. Using the above mentioned procedure; water leaving radiance images were generated for short wavelength channels of 412, 443, 490, 510, 550 and 670 nm. Rayleigh scattering and sun glitter components were also computed using method adopted by Mohan *et al* (1997).

Bio-Optical Algorithms for OCM imagery

A number of bio-optical algorithms for chlorophyll retrieval have been developed to relate measurements of ocean radiance to the *in situ* concentrations of phytoplankton pigments. An empirical algorithm (also known as Ocean Chlorophyll 2 or OC2, O'Reilly *et al.* 1998) has been used with IRS-P4 OCM data, on the basis of results of a study done on inter-comparison of different bio-optical algorithms. This algorithm was modified as per regional retrieval of chlorophyll concentration (Chauhan *et al, 2003*). It has been found that this algorithm captures the inherent sigmoid relationship between $R_{rs}490/ R_{rs}555$ band ratio and Chlorophyll concentration C. Where R_{rs} is remote sensing reflectance. The algorithm was shown to retrieve low as well as high chlorophyll concentration which means a better retrieval even in case 2 waters. The algorithm operates with five coefficients and has following mathematical form

$$\log_{10}C = 0.341 - 3.001 * R + 2.811 * R^2 - 2.04 * R^3 \quad \text{for } 0.01\ \text{mg/m}^3 \leq C \leq 50\text{mg/m}^3 \qquad (3.1)$$

where, C is chlorophyll concentration in mg/m^3 and $R = \log_{10} [R_{rs}(490)/R_{rs}(555)]$, where R_{rs} is remote sensing reflectance.

The chlorophyll concentration images were generated using above approach of processing. The software for generating chlorophyll concentration images are available for operational use at laboratory of Marine and water resources Group, Space Applications Centre, Ahmedabad. The sample output of chlorophyll concentration image is shown in Plate 3.1.

3.5.1.2. Analysis of NOAA AVHRR data

The brightness temperature sensed at satellite height is influenced mainly by atmospheric moisture. The signal loss due to water vapor absorption is proportional to the radiance difference in the measurement made at two different channels of the thermal infrared. The MCSST approach suggested by McClain (1995) was used to compute SST from AVHRR thermal infrared channels i.e. Ch # 4 (10.3-11.3 μm) and Ch # 5 (11.5 -12.5 μm). In order to estimate SST accurately, it is necessary to eliminate the influence of emission from clouds besides the precise calibration and navigation. Prior to the SST estimation, pixels of full-resolution images are discriminated into cloud-free pixels or cloud-contaminated pixels using a cloud-filtering algorithm, i.e. threshold tests for reflectance, brightness temperature and brightness temperature difference between the split-window channels. SST is estimated from the brightness temperature of cloud free pixels of the split-window channels using the following linear regression equation of the Multi-channel SST (MCSST) retrieval algorithm (McClain, *et al.* 1985).

$$SST = a \cdot T_{11} + b\,(T_{11} - T_{12}) + c\,(T_{11} - T_{12}) \cdot (\sec\theta - 1) + d \qquad (3.2)$$

where T_{11} is brightness temperature in 11μm band, T_{12} is brightness temperature in 12μm band, θ is satellite zenith angle, and a, b, c, and d are coefficients of the linear regression equation. The coefficients of the equation for each satellite and for daytime or nighttime are provided on the web site of National Environmental Satellite Data and Information Service (NESDIS) of NOAA. After the estimation of SST, the estimated value in each pixel is compared with the climatologically values of SST in order to eliminate unreasonable values of SST. If the difference between the estimated value and the climatological value is equal to or more than 5 degree K, the estimated value is rejected. The mean of the reasonable values of SST is calculated for each 0.25-degree square mesh and represents SST in each mesh.

Preliminary geometric correction was carried out according to Narayana *et al* (1995). This approach uses the satellite ephemeris. The precise geometric corrections were carried out using a set of ground control points (GCPs) located both on an image and on a Naval Hydrographic Office (NHO) bathymetric map.

This geo-reference master image was used for image to image registration of AVHRR channels in order to generate geo-reference data set. Color-coded SST images were generated which indicate the distribution of SST in the northwest Arabian Sea. Same color scheme was applied to both chlorophyll and SST images to make easy comparison between two parameters. The sample out put of SST image is shown in Plate 3.1.

3.5.1.3. Integration of chlorophyll and SST

Co-registration of OCM and NOAA AVHRR images - Geometric registration of both satellites data is major concern, particularly when the comparison between two different sensor data is to be made. For this, a master image was generated using GCPs located on an image as well as on a map. This was followed by map-image registration. Output master images were used to co-register chlorophyll and SST images in order to generate geo-coded images.

Generation of chlorophyll and SST composite

In order to visualize both parameters in the single product, chlorophyll and SST composite product was generated. For this, SST images were filtered to remove the noise using low pass filter. These filtered images were used to generate contours showing different SST (Plate 3.1). The contours were converted into vectors. These vectors were overlaid on chlorophyll images to generate chlorophyll SST composite showing chlorophyll and SST features / values (plate 3.1).

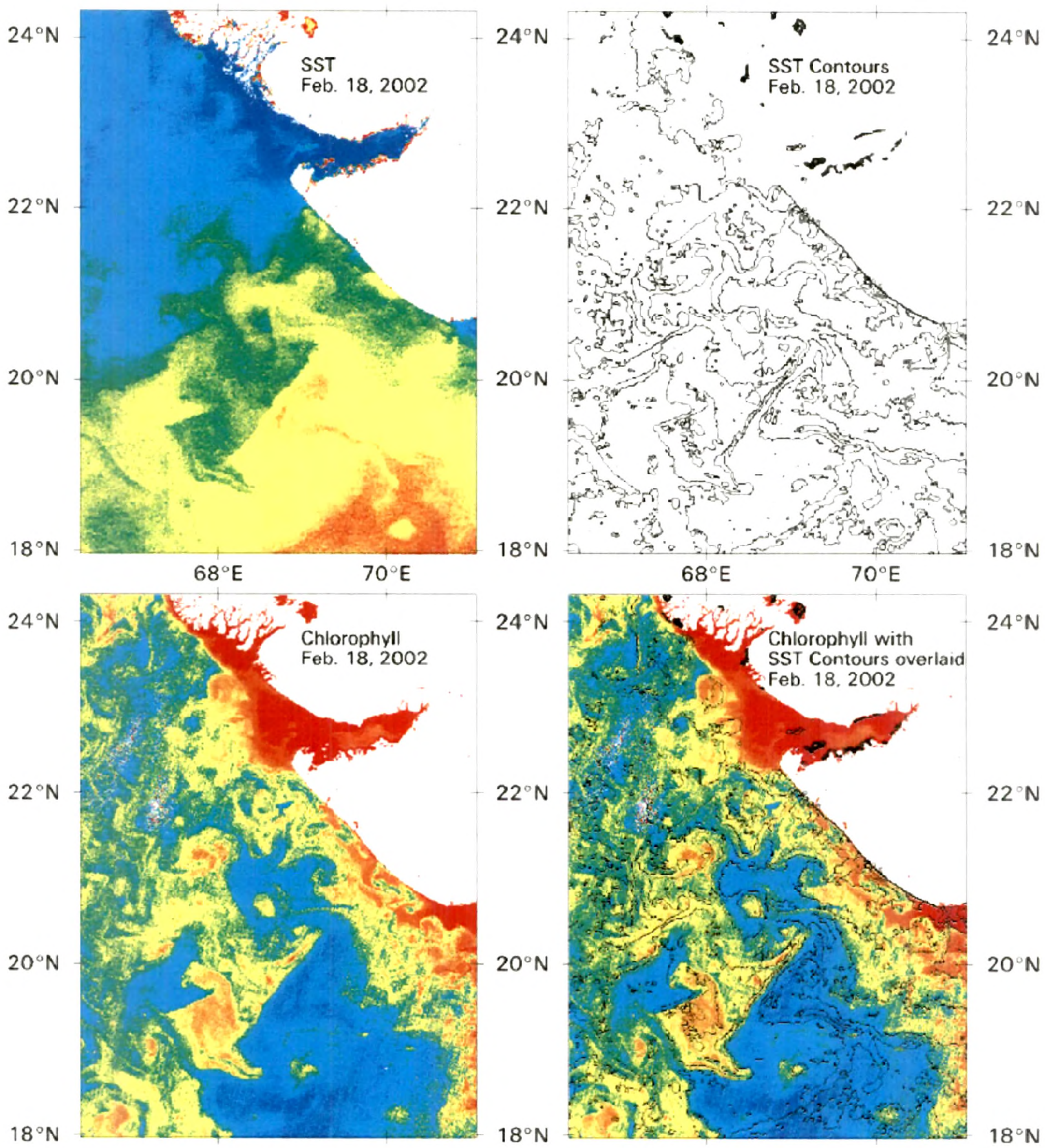

Plate 3.1: Typical out puts of SST, contour of SST, chlorophyll and composite of chlorophyll-SST generated through the step by step image processing procedure using integrated approach.

3.6. Interpretation chlorophyll and SST images

Comparison of oceanographic features

Oceanic features delineated on chlorophyll and SST images. Feature types such as eddies, rings, fronts with large gradients, meanders, etc. were identifies on both sensors' images. The comparable features were marked in the serial number in both sensor images. These features were compared in both chlorophyll and SST images for synergistic analysis of features types. The morphology of each feature was compared. The patterns of variability, persistence of features and their probable relevance to fishery resources distribution were studied. Archived fish catch was plotted on both images to relate the oceanic feature with fish catch. This ultimately helped in understanding feature types, and its relation to fishery resources distribution and to develop image interpretation key for locating potential fishing zones (PFZ)

Identification of PFZs -

Integration of chlorophyll concentration and SST was carried out in form of composite image as mentioned above. This chlorophyll and SST composite shows chlorophyll concentration in $mg.m^{-3}$ and SST contours in °C. Details of identification of PFZs and their selection criteria are well discussed by Solanki *et al.*, (2003, 2004). The features types selected for identification of PFZs, their scientific significance, selection criteria and their relevance with fishery resources distribution have been discussed in chapter 4.

3.7. Fish catch data analysis

The fish catch procured from Fishery Survey of India and Fisheries Dept., Gujarat State for the respective period of satellite data analyzed. Catch per Unit Effort (CPUE) for each fishing operation was calculated so as to normalize the fish catch. Two years (October 2000-March 2002) data were used in this study. Mean and standard deviations of each month were calculated to get monthly mean normal catch in the fishing areas. Catch points were classified based on mean (μ) and standard deviation (ð) of data set. The classification/categorization system was adopted to classify each point are shown table 3.9.

Table 3.9 Classification and category of fish catch based on fish catch statistics

Class	Range of distribution	Category
1.	< mean (μ)	very poor
2.	mean (μ) to (mean - standard deviation (ð)	Poor
3.	~ mean (μ)	normal (fair)
4.	mean (μ) to (mean + standard deviation (ð)	Good
5.	< mean + standard deviation (ð)	very good
6.	< mean + 2standard deviation (2ð)	excellent

Different circle sizes were assigned to each category for plotting the catch points on images. The catch points were plotted on images as per the geographic location of the fishing. Each point of fish catch was compared with the feature types to understand the relation of feature types on fish catch.

Species –wise catch data analysis

Fish catch data of entire study area was procured from FSI. Mean CPUE of identified PFZs area and other areas were computed and compared. The fish catch points found in vicinity of features were segregated and compared with monthly mean catch in other areas. Month wise and species wise comparison was made and presented in form of bar charts. The pattern of seasonal variability in fishery resources based on catch statistics was interpreted. A detail literature survey of food and feeding habitat of significant species in catch composition of study area was carried out and compiled (a compiled table and detail discussion is covered in chapter 4). This information was utilized to understand the link between fish distribution (habitat) and satellite-derived variables (chlorophyll and SST) and also to understand the fishery resources exploration capability of satellite sensors'.

The species wise percent contribution of fishery resources in PFZs and in other areas were computed based on mean CPUE and standard deviation in identified PFZs and seasonal CPUE of other areas. The per cent contribution of significant species of different habitat types were compared and interpreted with reference to satellite sensors' capability.

3.8. Impacts of surface wind on oceanographic features

This study emphasized on the application of QuikSCAT SeaWnds derived wind vector to understand the movement of feature due to wind driven circulation.

3.8.1. QSCAT-SeaWinds data analysis –

QuikSCAT Level 3 products produced by SeaWinds on QuikSCAT Science Working Team members were obtained from the PO.DAAC SeaWinds on QuikSCAT web site, http://www.podaac.jpl.nasa.gov/quikscat/. QuikSCAT-SeaWinds derived wind vectors were used to understand, establish, quantify and to demonstrate the variability of wind induced water mass flow as well as their impacts on features/oceanographic process.

Space borne scatterometers transmit microwave pulses to the ocean surface and measure the backscattered power received at the instrument. Since the atmospheric motions themselves do not substantially affect the radiation emitted and received by the radar, scatterometers use an indirect technique to measure wind velocity over the ocean. Wind stress over the ocean generates ripples and small waves, which roughen the sea surface. These waves modify the radar cross section (σo) of the ocean surface and hence the magnitude of backscattered power. In order to extract wind velocity from these measurements, one must understand the relationship between σo and near-surface winds — this relationship is known as the geophysical model function.

The SeaWinds instrument uses a rotating dish antenna with two spot beams that sweep in a circular pattern. The antenna radiates microwave pulses at a frequency of 13.4 GHz across broad regions on Earth's surface. The instrument collects data over ocean, land, and ice in a continuous, 1,800-kilometer-wide band centered on the spacecraft's nadir subtrack, making approximately 1.1 million ocean surface wind measurements and covering 90% of Earth's surface each day. The SeaWinds scatterometer design used for QuikSCAT is a significant departure from the fan-beam scatterometers flown on previous missions (Seasat SASS and NSCAT). QuikSCAT employs single 1-meter parabolic antennas dish with twin offset feeds for vertical and horizontal polarization. The antenna spins at a rate of 18 rpm, scanning two pencil-beam footprint paths at incidence angles of 46° (H-pol) and 54° (V-pol).

QuikSCAT SeaWnids level 3 data for the study was down loaded from NASA's website. This data consist of 25 Km^2 gridded values of scalar wind speed and corresponding meridional and zonal components of velocity. The U and V component data containing file is in HDF (Heirarchial Data Formate) format. This was a converted into ASCII format data file. The wind vectors were plotted using surfer software. Theses vectors were overlaid on the chlorophyll images.

3.8.2. Feature tracking and shift analysis –

Oceanographic features were delineated on the OCM derived chlorophyll concentration. Well-defined prominent features were identified and marked in the images. They were monitored using time series data. This allowed understanding the temporal variations in the meso-scale features. The displacement in terms of distance and direction were measured in the subsequent images. The observations of distance were used to calculate the speed of drift of each feature per day. Correlation analysis of between wind speeds of drift was performed to derive co-efficient. An algorithm was developed using these co-efficiants to estimate the shift in feature location of the feature.

3.8.3 Wind-driven currents and Mass transport

Steady winds blowing on the sea surface produce a thin, horizontal boundary layer and the Ekman layer. Effective frictional force exerted by the wind upon the ocean surface results in the wind-driven currents. These currents flow 45° cum sole the wind direction and the current velocity decreases rotating clockwise with depth.

For neutrally stable boundary layer, the stress exerted by the surface wind (at 10 meters above the sea surface) can be estimated for an approximate average air density (ρ_a) over the bottom boundary layer of the atmosphere (i.e., sea surface till 10m height) and using the relationship between the drag coefficient $(C_D)$and wind speed(W_{10}).In this study used variable drag coefficients suggested by Yelland & Taylor (1996), have been used to compute mass transport.

3.9. Secondary production modeling using remote sensing data

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. Coupled physical biological models can achieve a theoretical description of these complex processes. Chlorophyll concentration and temperature explain the coupled physical and biological processes. These two variables can be derived from satellite data. Ocean colour monitor on board IRS P4 and NOAA AVHRR data are used in this study to model secondary production.

Rao (1973) studied distribution of zooplanktons during International Indian Ocean Expedition (IIOE). The order of dominance was appeared to be, barring copepods that numerically form nearly 70% of the total samples of zooplanktons. Ecologically the copepods are major grazers in an ecosystem. The gut content analysis has shown that the developmental stages of copepod constitute 39-58% of diet of larval and post larval stages of mackerel. Hence, copepod availability is most important for the survival of larval stages of fishes feeding on secondary production, which are important for recruitment. Secondary production is missing link of food chain in present PFZs forecast technique in particular for carnivorous species exploration. More over for fish stock assessment it is expected to estimate secondary production to derive tertiary production rate and top consumers in an ecosystem. Hence the study would provide input for improving the present PFZs forecast and for stock assessment.

Looking into the advantage of remote sensing method for parameter retrieval, it is a logical progression therefore to search for methodologies, which use satellite data to provide estimates of secondary production. The copepod egg production model of Prestidge *et al.* (1995) provides such a medium. The model uses as input sea surface temperature (SST) derived from NOAA AVHRR and chlorophyll concentration data from OCM data to produce a species specific egg production (EP) rate; this is assumed to depend exponentially on temperature and to have a Michaelis-Menten relationship with the food concentration.

$$EP = Z_0 \, e^{\{(t-10)/\tau\}} \frac{P(t) - P(0)}{P(t) - Ph} \quad \text{when } P(t) > p(0) \qquad \text{\_\_\_\_\_\_\_\_\_\_ (3.3)}$$

Where,

Z0=maximum egg production rate at 10C,

T=surface temperature,

τ = temperature coefficient,

P = surface phytoplankton concentration,

P0=threshold phytoplankton concentration,

Ph = half-saturation phytoplankton concentration.

The model can be run for different copepod species by changing the parameters Z0, , P0,and Ph. Full details of the parametrisations can be found in Prestidge *et al*. (1995).

Plate 3.2. indicates the schematic presentation of methodology. The egg production rate may be utilized for computation of secondary production using CPR or OPR in-situ observations. The secondary production may convert into food availability for fishery resources through proper assumption and modeling.

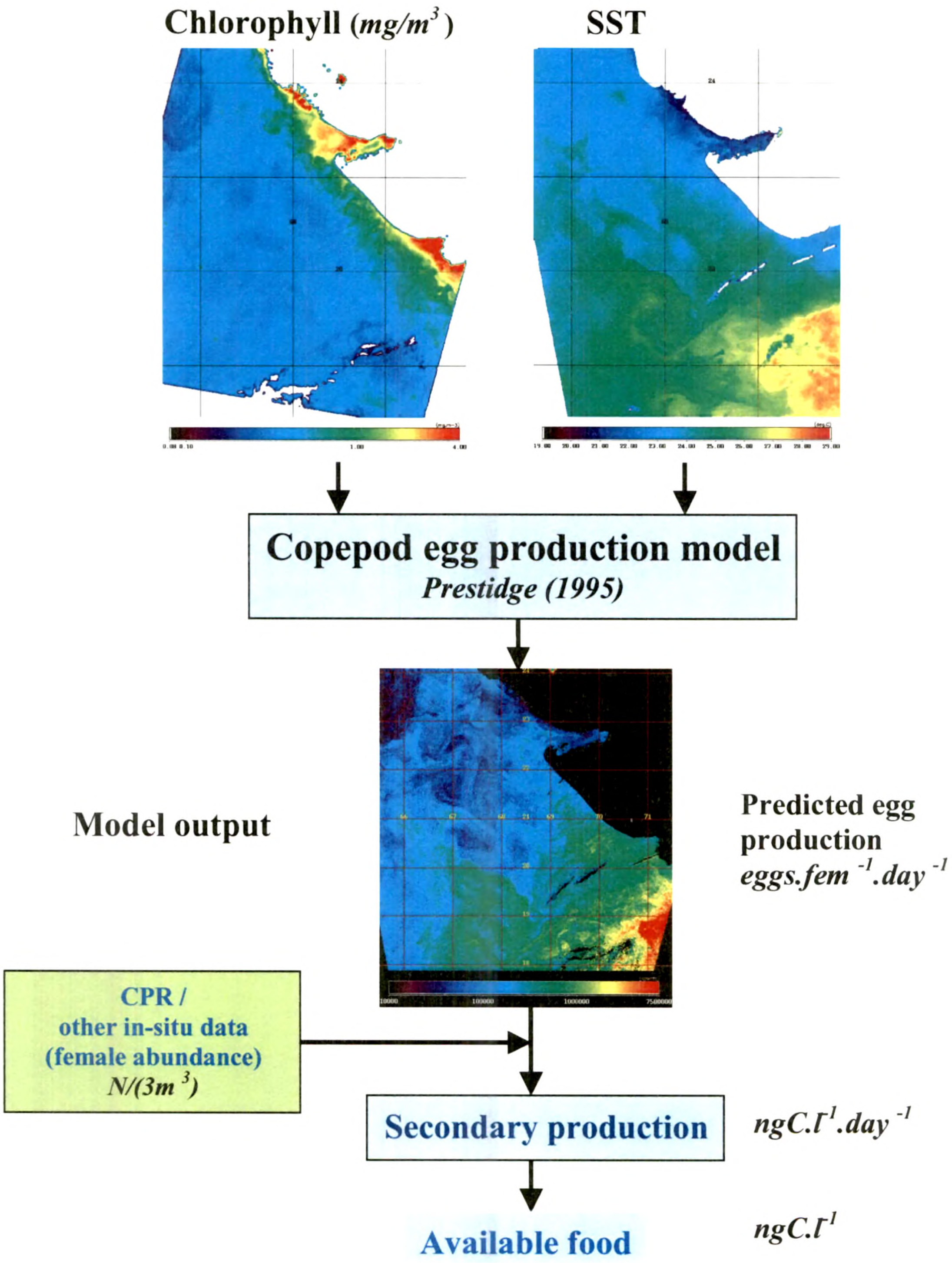

Plate 3.2: Schematic diagram showing procedure to determine secondary (2°) production using a combination of satellite derived parameters modeling and CPR data