CHAPTER 3

ABIOTIC THREATS:

Sedimentation

3.1 Introduction

Much of the current reef research around the world is focused on tracing the roots and relations of episodic events like that of the Mass Coral Bleaching of 1997-98 to issues and indicators of global warming and climate change. As a result, this has overshadowed discussions on sedimentation, an otherwise chronic and widely acknowledged threat to coral reefs (Buddemeier and Hopley, 1988; Bryant et al., 1998). Sedimentation per se is a natural process, and, if viewed in the context of the global sediment budget, also shows a link to global warming if carefully correlated with increased glacier melt and terrestrial run-off. Nevertheless, the problem of sedimentation can also occur, and is accelerated by, anthropogenic impacts (Singh, 2006).

The presence of suspended sediments in a reef environment is common, and the reef itself is a 'Bioherm'– an organogenic framework of calcium carbonate, secreted by the hermatypic coral polyps, that acts as a source of carbonate sands (Cumings, 1932). These sediments remain either in suspension or settle onto the reef. They become a stress for Hermatypic (reef-building) corals when their proportion exceeds the normal tolerance threshold for corals. As corals are delicate, coelenterate organisms, they require clear, transparent water for their survival and growth. Episodic or long-term sediment influx in the reef environment has a gradual deleterious effect on coral communities, as it blocks the sunlight penetration to the photic depths, thereby considerably modifying the ambient underwater light field. The functionality of the reef ecosystem strives on the tight nutrient cycling between the host coral polyps and its endo-symbiont photosynthetic algae, zooxanthallae. Suspended sediments thus change the availability of PAR within the photic zone, hindering the photosynthesis of zooxanthallae, resulting in a low supply of nutrients to the host coral polyp. The drop in the symbiotic nutrient cycling leads to an overall decrease in the coral's growth, as well as the subsequent reproduction and recruitment processes (Hubbard, 1986; Rogers, 1990; McCulloch et al., 2003; Goldberg and Wilkinson, 2004; Jordan et al., 2010).

To combat the smothering (blocking the availability of dissolved oxygen in water) and abrasive effects of sediments in their corallum, corals try to remove sediment particles through their active tentacular movements and high epidermal mucocilliary system (Edmondson, 1928; Yonge, 1930; Lewis, 1973; Lewis and Price, 1975; Coffroth, 1983; Abdel-Salam et al., 1988; Edmunds and Davies, 1989). Sediment removal from the coral polyp demands high energy utilization by the coral which is otherwise meant for its other physiological activities. Sedimentation affects the reproductive success and the recruitment probability of new larvae (Hughes et al., 2003; Fabricius, 2005). The planktonic larvae of corals and many other reef invertebrates cannot settle to colonise on the soft, shifting sediments. In sheltered areas where currents are not strong enough to remove the sediments, recolonisation is prevented indefinitely. Sediment particles even induce internal and external tissue damage and sometimes result in localized tissue bleaching (Anthony et al., 2007). Thus, sedimentation in a reef environment decreases the overall biological productivity of the entire ecosystem (Sanders and Baron-Szabo, 2005).

Sediment loading in a coral reef environment can be viewed with reference to the sediment source and the physical oceanographic processes. Release of autochthonous sediments within the reef-system is a natural process, primarily a result of the continuous, physical factors (waves, tides and currents as major identified agents) and bio-erosion, along with the concurrent weathering processes of the dead coral reef, boulders and debris (Cumings, 1932). An event of oceanic eddies and turbidity currents also sometimes contributes to the sedimentation problem by affecting the local sediment budget with a sudden influx and disturbance of normal sediment flow or movement, dispersion, and settling rates and patterns. The effects of sedimentation in a reef environment worsens with terrigenous inputs of fine-grained sediments commonly discharged from terrestrial rivers and erosional run-offs resulting in high turbidity and subsequent siltation (Kunte et al., 2003; Field et al., 2006; Ramaswamy et al., 2007). Anthropogenic factors that contribute to degradation of the reef environment result from a myriad of developmental activities, especially in the coastal zone. Dredging and blasting of reefs for the construction of jetties, harbors, ports, or any kind of coastal or shore protection structures like groins and breakwaters are the most common human activities which directly destroy the living reef within a short time or indirectly alter the reef habitat over a longer period (Maragos, 1993).

Conventional, field based methods of boat or ship borne data collection, while providing accurate measurements, have the disadvantage of being individual, small, site-specific studies which sometimes fail to provide a comprehensive reef-scale picture. In this context, an alternative approach can be adopted using a multi-temporal sequel of high spatial resolution, multi-spectral satellite images. The digital data is used as an input to identify litho-substrate characteristics and map reef-scale morphodynamics. Reef scale morphodynamics are considered a key to understanding the changing hydrodynamic conditions of the reef and predict the sedimentation patterns and processes operating on the reefs.

Reef research based on satellite-borne, optical remote sensing has evolved over the last three decades, primarily in the realms of habitat mapping and health monitoring, with a strong synergistic contribution from sensors designed for both land and ocean observations. With the increasingly available combination of higher spatial resolution and broad spectral bands in the visible and infra-red (IR) regions of the electromagnetic spectrum, coral reef remote sensing has attained a significant success in habitat mapping as characterization of reef geomorphology and major ecological/benthic substrates. Health monitoring of reef ecosystems using these habitat maps has become a popular approach. By providing repetitive, synoptic, reef scale coverage, remote sensing techniques are useful in comprehensively monitoring the problem of sediment loading in a reef environment.

3.2 Objectives

This aspect of the study aimed to identify micro-level regions vulnerable to future sediment loading of Pirotan Reef, identified as a core area of the Marine National Park, Gujarat, India.

In order to achieve this aim, this study attempted to:

i) Identify litho-substrate characteristics of Pirotan reef
ii) Map reef scale morphodynamics to facilitate an understanding of the changing hydrodynamic conditions of Pirotan reef
iii) Monitor reef scale sedimentation patterns and predict sedimentation processes

3.3 Study Area

3.3.1 Physical Settings

Pirotan Reef (22°34'41" - 22°37'06" N latitude and 69°55'54"- 69°58'57" E longitude), identified as the core area of Marine National Park (Jamnagar district, Gujarat, India), is situated on the Jamnagar-Okha coastal segment of the Saurashtra Peninsula. It is interiorly located in the southern part of the GoK, in a macro-tidal and highly turbid environment in the west coast of India. Pirotan is a fringing type of reef with an island at its core, and lies north of Jindra bet island, and to the North-West of Munde-Ka-Bet reef **(Figure 3.1)**. Pirotan is exposed to a semi-arid, low rainfall climate, with sluggish terrestrial streams and low detritus load. It has hypo saline and turbid waters with moderate to high tidal (3-5 metres) range. Although wave action is low, they represent fairly high tidal energy conditions. The principle littoral zone material consists mostly of calcareous mud with occasional sand and clay (Merh, 1995). All these features of this coastal segment offer an ideal situation to study the reef response to sedimentation processes at a habitat as well as species level.

Among all the coral reefs located in this coastal segment, the location of Pirotan reef is unique. It is separated from the main coastline of Saurashtra Peninsula by the presence of Jindra bet island to its south. Hence, it remains away from the localized tidal circulation of any micro-bays curved out of the coastline crenulations that are otherwise common in this coastal segment. It remains as a projected headland just on the southern margin of an abrupt narrowing of the width of the East-West oriented GoK at 70° 20'E (Wagle, 1979).

3.3.2 Early History of Sedimentation

Satellite imagery-based early records of Pirotan reef show a narrow, East-West transverse belt, adjacent to the central island, of mud deposition over the reef in a 1975 image (Bahuguna et al., 2007). Within the next fifteen years, there was considerable extension of mud deposition in the eastern part of the reef. Over the short three year period from 1982-85, mud deposition over the reef transpired a particular pattern: a gradual, North East-South West orientation of the mud-spread along the eastern margin of the reef. Over the time period 1990-2008, although the gross pattern of sedimentation has remained the same, there has been a gradual obscurity of the eastern margin of the reef under a column of mud. Interestingly, however, the relative spatial occupancy of sand and mud over time demonstrates a high dynamicity.

3.4 Materials and Methods

3.4.1 Data

Two types of data have been used in this study.

3.4.1.1 Satellite-borne remote sensing data

Multi-spectral images of Pirotan reef from the LISS-IV sensor of the Indian Remote Sensing satellite RESOURCESAT (IRS-P6) have been used to study the reef-scale sedimentation pattern for a period of four years from 2004-2007 (**Table 3.1**).

This four year sequel for Pirotan reef has been archived with a single-date, low-tide image data set as a representative of the yearly condition (**Table 3.2**). Care has been taken to combine information of different seasonal conditions from the archived data set.

3.4.1.2 Tide Data

As coral reef remote sensing depends on low tide exposures of the reef, tide data corresponding to satellite image acquisition, available from the Indian Tide Tables, was referred for analyzing the prevailing tidal conditions for three reference tidal stations: Okha, Kandla and Navlakhi (**Figure 3.1**).

3.4.2 Methodology

A diagrammatic representation of the methodology has been given in **Figure 3.2**, and an explanation of the same has been given below.

Resoucesat-1 (IRS P6), LISS-IV image data (in precision geo-coded, digital data in Geo-Tiff format) for Pirotan Reef were archived and visualized as standard FCC (**Figure 3.3**). Using the standard formula to convert the pixel level Digital Numbers (DN), the digital images were converted into radiance images. Dominant ecological and lithological substrates were identified, and a minimum of 10 randomly sampled pixels' radiance value were plotted against the spectral channels. This generated the Spectral Signature for understanding the response of these different substrates in the three broad spectral channels present in the LISS-IV sensor. **Figure 3.4** represents the typical spectral signatures of different litho-substrates present on the reef, namely sand, mud, sand and mud together, water in the shallow tidal pool, and that of the reef flat, which is a zone of assemblage of different litho and benthic substrates. The graph shows the spectral signature of various reef substrates. On the basis of understanding of the spectral signatures, the digital images were subjected to automated Unsupervised Classification module, available in the software following a maximum likelihood classifier approach. Classified raster images were used as an input to quantify the relative area occupancy of different substrates **(Figures 3.5 and 3.6)**

Vector polygons representing different geomorphic zones and ecological units were created for the core area for all four years. This was to enable change detection in the core area of the reef overlaying vector maps of the current year on the preceding year. Thus, change detection maps **(Figures 3.7, 3.8 and 3.9)** of the core region were prepared to analyze the trends of morphodynamics.

To correlate the trends of morphodynamics with the hydrodynamic conditions prevailing on Pirotan reef, flow lines were traced for 2004, 2005, 2006 and 2007 conditions to carry out similar change detection through overlay technique. Thus change detection maps for flow lines were generated for 2004 versus 2005, 2005 versus 2006, and 2006 versus 2007 conditions (**Figures 3.10, 3.11 and 3.12**).

To correlate the predicted hydrodynamic conditions with the prevailing tidal conditions at the time of image acquisition, Survey of India (SOI) Tide Tables for the corresponding dates were referred and tide graphs were generated (**Figure 3.13**) for the three tidal stations of the GoK: Okha, Kandla and Navlakhi.

The sedimentation pattern and processes operating on Pirotan reef are discussed in the light of reef-scale morphodynamics and hydrodynamic conditions of the reef. On this basis of understanding a map depicting the future scenario of Pirotan overlaid on the 2007 image has been generated (**Figure 3.14**) and accordingly reef-scale micro-habitat level changes have also been predicted.

3.5 Results and Discussion

Morphodynamics represents the change in the 'morph' or the landform. In any coral reef environment, hydrodynamic conditions and morphodynamics can be studied to understand the flow patterns of water. The core region of Pirotan reef was chosen to study the morphodynamics in order to understand the flow of water.

3.5.1 Change Detection of Core Zone

3.5.1.1 Change Detection of Core: 2004 versus 2005 scenario (Figure 3.7)

A narrow beach strip in the North Eastern part of the core was observed in 2004. Extension of this beach was in the North West-East direction. A decrease in mangrove cover and an increase in the High Tidal Mudflat (HTM) were also observed. HTM occupied a mangrove dominated core part in 2005. There was a decrease in the mangrove cover in the arm-like structure in the west in 2005. In the South-Eastern part, the beaches extended in 2005 with a direction North East to South West. In 2005, there was a subtle increase in the beach prominence and extension in the South-Western part.

In summary, from 2004 to 2005, there was a decrease in mangrove cover. The mangrove zone turned into HTM, indicating that water was not able to reach the mangroves to sustain them. This implies that there was an increase in the slope and extension of the beaches, indicating stability of the beaches.

3.5.1.2 Change Detection of Core: 2005 versus 2006 scenario (Figure 3.8)

An increase in the width of the North East part of the beach showed a slight pro-gradation. However, the western side shrunk and this change was also noticed in terms of beach sand removal on its eastern side. The area of the original HTM has decreased, and the earlier thin beach has extended inside. Overall, there was a decrease in the mangrove cover in the south and the thin line of sand ridge, almost running parallel to the southern margin of the mangroves, shows prominence, indicating that the volume has increased. In the eastern and southern part, extension of the beach was noticed in the North East to South West direction. However, a small gap separated these two beaches. The beach on the pool-side did not show any change, although its extension over the HTM into the interior continued. The mangrove arm showed an increase, as in 2006, and there was a slight increase in the mangroves of the arm on the west.

3.5.1.3 Change Detection of Core: 2005 versus 2006 scenario (Figure 3.9)

The beach in the North East sector now showed a considerable decrease on its eastern and western flanks, indicating relocation of sand from this beach followed by scouring action of the tidal waves. The HTM in the inner core was fragmented in the northern sector, and colour variation in the HTM suggests evidence of salt encrustation on the previous HTM. The line of the beach in the entire western margin remained the same whereas the thin sand ridge showed a similar prominence. The extension of the beach segments in the central region showed a gradual merging, indicating a change. The mangroves in the arm and the fragmented patches showed a slight decrease in their vigour. This was because of shelter provided by the beach in the southern part.

3.5.1.4 Summary: Change Detection of Core 2004-2007

The morphodynamics of the core region indicates a micro-level change in the eco-geomorphic system in terms of the following.

There was a decrease in the mangrove cover in the core region, indicating a shortage in the availability of tidal water in terms of frequency and volume, as well as residence time of water of the tidal inundation. The areas losing out the mangrove cover were subsequently turning into HTM. The HTM was being fragmented over time and from 2006-20007, the HTM showed evidence of salt encrustation. The core region was in the process of being isolated, with an increased level of beach deposition. From 2004 to 2005, there was a stark contrast in terms of sand influx, whereas from 2005-2007, the direction of sand movement was different and there was relocation. There was a new deposition of sand seen in the eastern part, which could be considered as a juvenile beach.

3.5.2 Change Detection of Flow lines: Hydrodynamics

Flow line change detection has been carried out sector wise. The entire reef area has been divided into seven sectors on the basis of local slope and flow line direction (**Figures 3.10, 3.11 and 3.12**).

3.5.2.1 Sector A

In this sector, the slope is from the beach to the pool. Principal flow direction is from the beach to the pool. Main flowlines are almost doubled and the number of segments is reduced. The overlapped length of permanent flowline and the segment indicates the seasonal flow in the channel. Partial overlap of segments indicates the subtle depression in their length of flow. Interfluves were initially 14 and have now increased to 22, indicating an increase in the number of flows dissecting the earlier interfluves. Hence, this indicates that, in post monsoon conditions, the increased volume of water creates more channels, and their depressions remain alive until winter when more volume of water is pumped into the system. Two streams even showed landward extension. The volume of water seems to be important in maintaining the flowlines, and the change in slope factor controls their distribution, length and flowlines. Interfluves show a decrease from 22 to 17. The most surprising observation is virtual absence of any stream or flowlines in the northern part of this region and it continues from 2006 to 2007. Even the channels observed in 2005 do not show a trace, even in segments of their previous flow lengths. Hence it can be observed that the sand filling of the pool has completely erased the gradient of this part, and has made it an extremely smooth, flat surface, with not even a single ebb channel present.

Towards the South-East part of sector A, there runs a network of parallel flowlines aligned in the South East to North West direction. These flowlines and interfluves show complete or partial overlap from 2006-2007. Statistics show that the overlap over the length of the flowline continues even with different seasons in this region. From 2006 to 2007, the overlap shows a cutoff mostly in the headward direction, whereas their poolside segments show a consistency in water retention.

3.5.2.2 Sector B

Sector B shows dynamicity in terms of depositional features observed over time in different seasons. In 2004, the principal stream numbers were 10 with 11 interfluves, and this increases to 26 interfluves with 5 principal and 23 segments in 2005. In 2006, the interfluves increase to 30. This indicates that with an increasing volume of water, the number of channels and small depositions increase over time, merging with each other and increasing in size. What is also noticeable is the disappearance of the streams in between the mangrove arm and the pool, suggesting smoothening of the slope in this region.

3.5.2.3 Sector C: Pool Morphodynamics

Adjacent to the central core, there is a shallow tidal pool. This tidal pool shows sediment filling from 2004 to 2005. It also shows that there is an "S" shaped juvenile beach in the process of forming, with two convex heads – one on the north and one to the south. There is also a series of linear North West-South East sand ridges and gullies. In the southern part of the pool, there are fragmented sand patches criss-crossed by gullies.

In the northern part, there is considerable extension in the juvenile beach width. However, immediately after the central concavity, the width is reduced and thus the series of sand ridges and gullies gradually merge with each other. Furthermore, in the central concavity of the 2006-2007 scenario, there is a cover of matty algae, indicating a relative stability of the deposits with reference to the operational tidal regime. A small sand patch, which also can be termed another juvenile beach, is forming between the extension of the southern beaches of the island core and the "S" shaped juvenile beach rising out of the pool. Numerous small sand cays are observed on the seaward side of the pool on the inner reef flat for 2005-06. In 2007, they all merge. These sand patches act as interfluve areas cut off by tidal gullies on their either side. The 2005-06 scenario shows a veneer of mud on them, colonized by matty algae. This, however, is washed off in 2007.

The morphodynamics of the tidal pool shows a correlation with the changing scenario of the central core. The beach extension process complements the pool-filling process, and there is strengthening of the S-shaped juvenile beach of the pool with a continuous supply in the sediment volume. The relocation of beach sands onto the pool is well understood with reference to the narrowing down of the beach at the core in the North-

East sector. Hence it can be inferred that the beach surrounding the entire core region is acting as the source of sedimentation for this tidal pool. The changing scenario at the core has definitely changed the hydrodynamic conditions of the core. There is extensive pro-gradation of the beaches onto all sides and changes in the slope, which restricts water movement to the central core. Hence the active hydrodynamic regime is now operational on the pool.

3.5.2.4 Sector D

The entire sector D is a mud-draped area with an approximately 1-2 metre thick mud column (Bahuguna et al., 2007). The number of principal streams and interfluves show a positive correlation with seasonal influx in the water volume. However, this increase in the segmented flowlines can be a result of the rise in the mud column over the time period, and may result in blocking the length of flow over a period of time. The overlapped length increases with the retention of the volume of water, whereas partial overlaps, especially on fragmented flowlines, indicate the more proper areas of the channels. Hence, it can be inferred that the rate of siltation is consistently high in this area.

3.5.2.5 Sector E

Sector E appears to be a relatively new area of sedimentation and shows evidence of new depositions of mud. This is unlike sector D, where a mud draping process is consistently on. The transition from 2004 to 2005 can be marked as the year of change. Thereafter, the changes, both in the number of main flowlines and interfluves, remain almost constant. Only the flowlines segment numbers increases steadily. This change can be attributed to a change of season. Although, their stability continues thereafter.

3.5.2.6 Sector F

Sector F is basically a miniature creek network connecting the southern part of Pirotan Reef with the adjacent island of Jindra bet to its south. A mud island separated by two major creeks stands in between Pirotan reef and Jindra bet. As the flowlines in this sector are basically creeks of different dimensions, an overall stability in their existence is observed. The numerous, small segmented flowlines may be a result of an ebbing tide in 2005, 2006 and 2007, rather than due to seasonal dynamics. Some of the major flowlines are long enough to sustain flow with a fair width dimension showing potential to become future creeks. However, the difference in their bathymetry, due to siltation, controls development of these future creeks.

3.5.2.7 Sector G

This sector, located on the eastern part of Pirotan reef, shows a mixed influence of sand deposition and siltation governed by hydrodynamics and slope. That part of the sector that lies close to the extending beach towards the North-East shows more an influence of sandy deposition and flowlines originating almost from the foot of the beach. Two major creeks protrude inside the reef. Extensive mud deposition can be understood from this flow pattern. Two distinct slope zones can be observed i) just beneath the beach, dominated with parallel West-East aligned flowlines and interfluves and ii) towards a reef edge, a zone of extensive mud deposition cut across by different West-East running flowlines. These two zones are separated by a mixed zone of sandy deposition draped with mud as a zone of confluence. The flowline and interfluve numbers show a steady increase with time showing a seasonal effect in the hydrodynamics. However, the interfluves decrease in number indicating their gradual merging with each other (**Table 3.3**).

3.5.3 Tidal Conditions

Since hydrodynamics and sedimentation processes can never be understood in isolation from information on tidal conditions, the observations drawn from maps prepared from satellite images are analysed in light of prevailing tidal conditions at the time of satellite pass. SOI Tide Table data have been used to construct the tidal conditions for a small window period of five consecutive days with the day of satellite pass as the third day. Tidal conditions of three major ports, Okha (22°28'N, 69°05'E), Kandla (23°01'N, 70°13'E) and Navlakhi (22°88'N, 70°27'E) have been used to understand the satellite imagery based observations for Pirotan (**Figure 3.13**). The graph shows the tidal conditions at Okha, Kandla and Navlakhi during Resourcesat IRS-P6 LISS-IV Mx Pass. This indicates that the images of 2004, 2005 and 2006 have been captured at the mid of an ebbing condition, while in 2007 the image acquisition synchronizes with the start of a flooding condition. This graph also confirms that Okha, situated almost at the mouth of the GoK in the south, has a tidal range of four metres. Kandla (situated on the northern Jakhau-Kandla coastal segment of the Kachchh peninsula) and Navlakhi, on the other hand, situated at the eastern end of the Gulf, have a higher tidal range of seven to eight metres because of their inland location. The relative location of these three tidal stations also results in a phase lag of 120 to 165 minutes (Deshmukh et al., 2005). Studies on GoK sediment dynamics have supported the concept that the sediment movement within the GoK is in the South East to Eastward direction. With tidal propagation in the flooding phase, sediments move inwards towards the head of the Gulf, and while in the ebbing, the sediments are flushed outside along the southern coast of the Gulf.

The sedimentation processes occurring at Pirotan reef is in accordance with the regional sediment movement pattern of GoK. As a result, a North East-South West trend line demarcating a clear distinction between the relatively, sediment-free seaward face of the reef and the contrasting Eastern and South-Eastern areas showing high sediment loading (mud deposition) is evident (**Figure 3.14**). This pattern can be further detailed as following:

- The morphodynamics of the Pirotan reef during 2004-2007 has helped in understanding the establishment of substrates and the sedimentation pattern and distribution.
- Substrates have undergone changes in occupancy as well as condition.
- Reef Flat is observed to have undergone degradation and decline.
- Spread Zone for Sand in the reef region is increasing annually.
- Water Pools are decreasing, and sand filling in the pools has been observed.
- There is a significant increase in the extent and spread of matty algae. This increase has also coincided with high temperature anomaly years. Similar observations have been recorded from Paga reef.
- Sand over mud area is also increasing as sand spreads over mud easily and thus produces small juvenile beaches, indicative of the stabilization of the mud underneath.
- More water channels are present on the South-East and Southern part, which has a major effect on siltation. In contrast, in the North-West direction, the major effect is due to sand filling. The Healthy Reef Flat region of Pirotan is observed to be devoid of any channels, whereas the degrading reef portion has significant channels.
- The channels are responsible for deposition as well as flow direction of sediments on the Reef.

- The extensive mud deposition onto the eastern part is attributed to the factors of regional tidal and sediment dynamic. Changes in sedimentation patterns are leading to micro-level changes in the ecosystem and relocation of organisms from their original habitats to new habitats.

3.6 Future Projections

If the sedimentation pattern on Pirotan reef continues along the same trend that has been observed over the past few years, it will result in a definite loss in the reef flat area. The central shallow tidal pool, which is in the process of sand filling, will eventually become a sand filled area. The trend line separating the sand and mud will however be sustained under the regional hydrodynamics and sediment dynamics of the GoK. The morphodynamics of core affects the sedimentation process in the pool, while the flooding and ebbing pattern on the eastern side and the proximity to Jindra bet affects the extensive mud deposition. In the long run, this region is likely to turn into intertidal mudflat. The hydrodynamic regime in the core zone of Pirotan reef has changed. This is based on the decreasing and degrading mangrove conditions. Eventually, it is likely that this core zone will become a high tidal mudflat area lined by beaches on all sides. The interplay of hydrodynamics and morphodynamics in turn may alter the ecosystem at the micro-level. The micro-habitat changes from mangrove to high tidal mudflat, reef flat to sanded reef flat and eventually grading with beaches, and shallow tidal pools to sandy-muddy interfluves, will eventually result in obvious changes to the ecosystem. As a result, the earlier zones colonized by certain benthic communities will be colonized by different ones according to the defined animal-sediment relations.

3.7 Conclusions

This chapter detailed the geology of Pirotan reef. An integrated approach was taken to understand the reef, its threats, and the effects on its biota. As discussed, the future of the GoK reefs is not expected to be healthy due to the existence of heavy sedimentation, which has left its mark on almost all the reefs of the region. This poses a significant threat to the reef biota.

It is known that animals have close relations with their habitats and baseline substratum. Changes in habitat alter the ability of specific organisms to reside in the new environment. In the case of Pirotan reef, habitat alteration is progressing at a rapid rate, which prevents an organism from adapting to new surroundings or moving into another area. This creates an imbalance in the fragile ecological balance, and can lead to the collapse of the entire ecosystem. This has multiple short and long term effects on the ecology, biodiversity and economics of the region. Regular monitoring of this most northerly located reef is thus essential. Remote sensing provides a useful technique for this ongoing survey. Although it does not provide quantitative information about biotic diversity, it does provide general information on the condition of the reef. Based on that information, a reef scale picture of the biota can be created. **Figure 3.14** presents a possible future scenario of Pirotan reef along with locations of current biotic diversity. Furthermore, field observations that indicate the correlation of such prediction maps and field photographs of the various substratums have been shown in **Plate 3.1**.

By using RESOURCESAT IRS P6 LISS IV data to monitor the problem of sediment loading, it is clear that a space borne remote sensing technique to study reef scale sedimentation patterns and processes is effective. The move from a mapping to measurement concept means that the morphodynamic and hydrodynamic changes can be more rigorously quantified. As a result, this approach allows sedimentation problems on even small reefs to be addressed with pattern and process studies. Future scenarios can be predicted, and with the established knowledge of animal-sediment relationships, ecological changes with changes in the benthic community structure can also be predicted.

This kind of information, modeled on a GIS platform, may facilitate the community of reef researchers, especially biologists and ecologists, to pre-plan sample sites for field data collection. Data generated from these studies can also be used by planners and managers for the proper management of these sensitive ecosystems and critical habitats of coastal zone.

Table 3.1 Specifications of the RESOURCESAT IRS P6- LISS-IV Sensor

Satellite	Sensor	Spectral Resolution	Radiometric Resolution	Spatial Resolution	Temporal Resolution
RESOURCESAT IRS P6	LISS IV	Channel1: Green (0.53-0.58 nm) Channel 2: Red (0.62-0.68 nm) Channel 3: NIR (0.77-0.86 nm)	7bit	5.8×5.8 m	24 days

Table 3.2 Details of Data used for Pirotan reef

Sensor	Date of Acquisition	Orbit	Scene	Season
LISS IV	23 May, 2004	03113	86	Onset of monsoon
LISS IV	04 January, 2005	6324	75	Winter
LISS IV	28 October, 2006	15730	96	Post Monsoon
LISS IV	06 February, 2007	17165	98	Winter

Figure 3.1 Location Map of Pirotan reef and Tidal Stations with Hydrodynamics of the Gulf of Kachchh

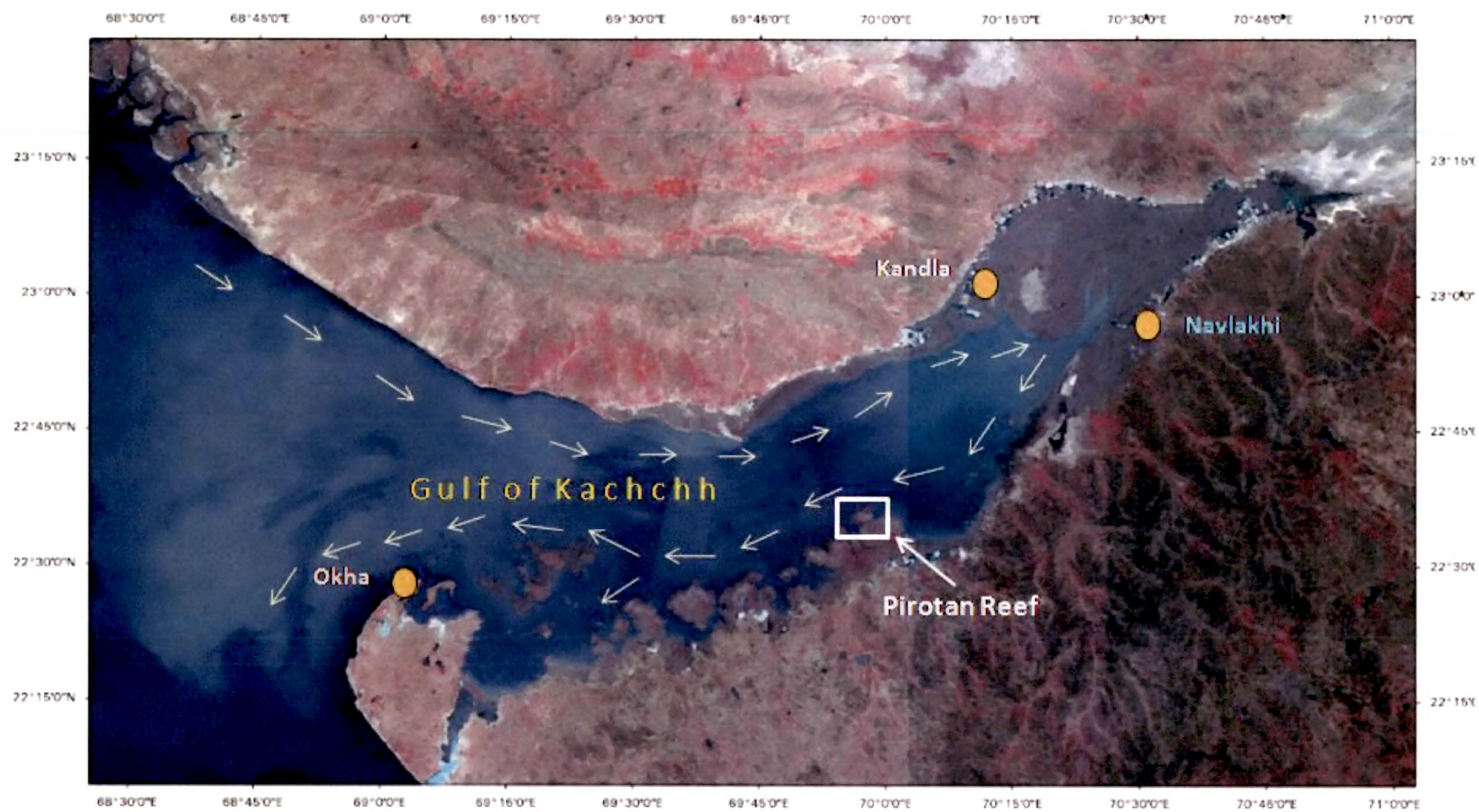


Figure 3.2 Flow chart of Methodology

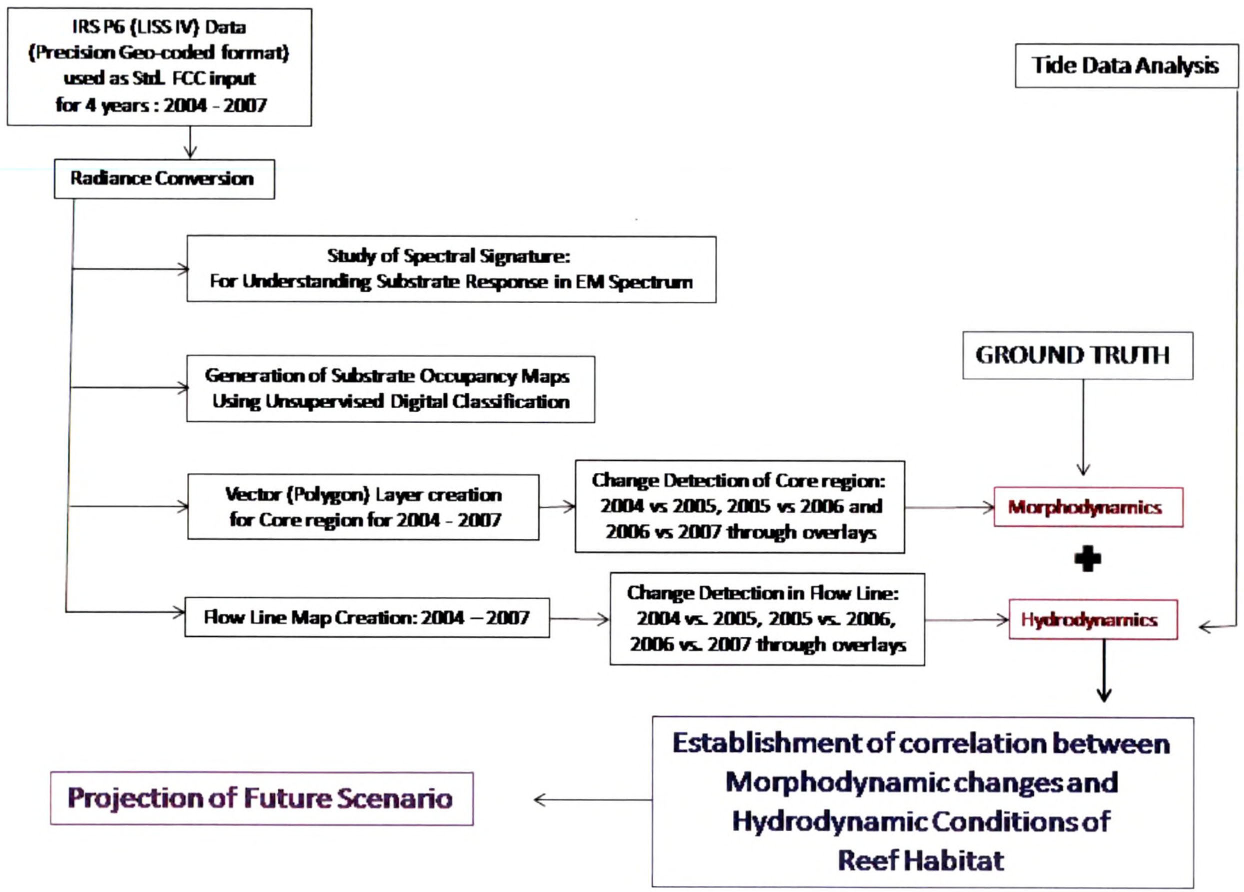


Figure 3.3 RESOURCESAT (IRS P6) LISS IV Images of Sequential Years 2004 to 2007

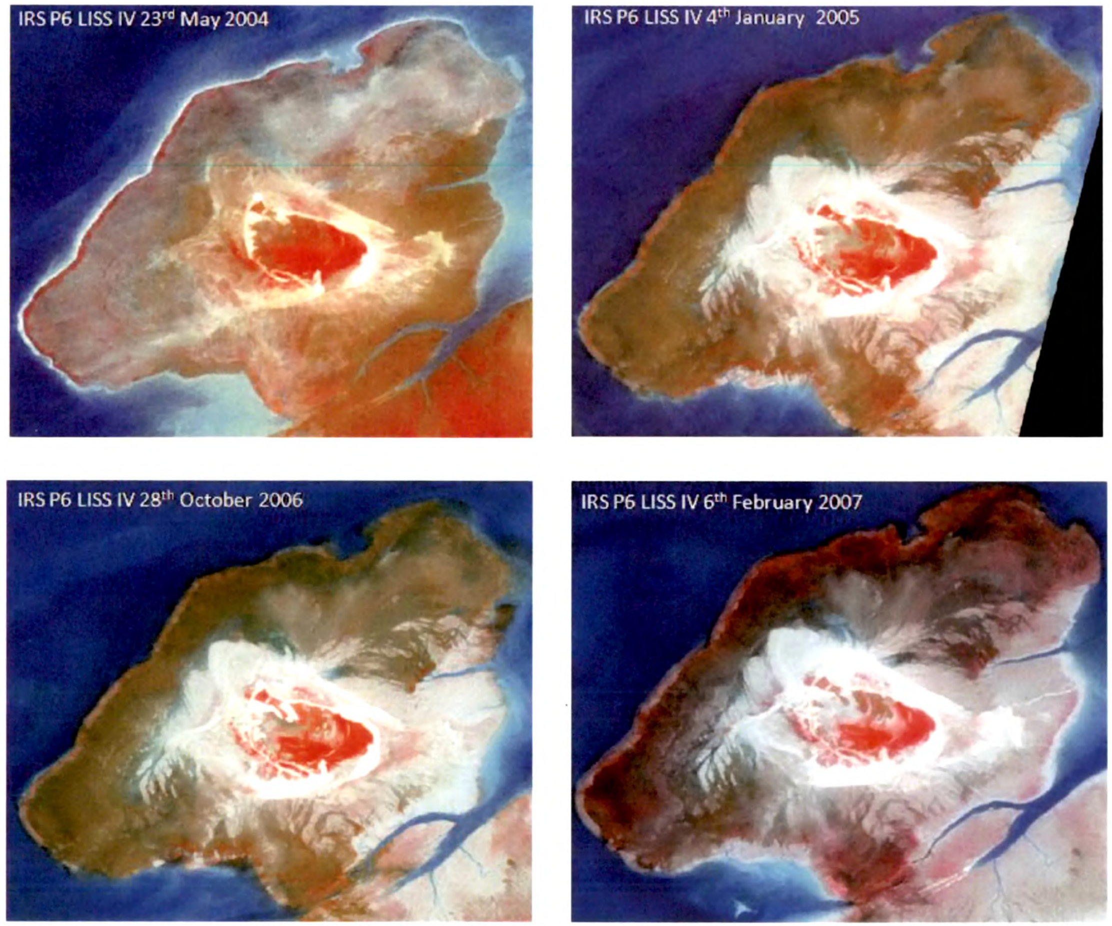


Figure 3.4 Spectral Signature of selected Reef Substrates

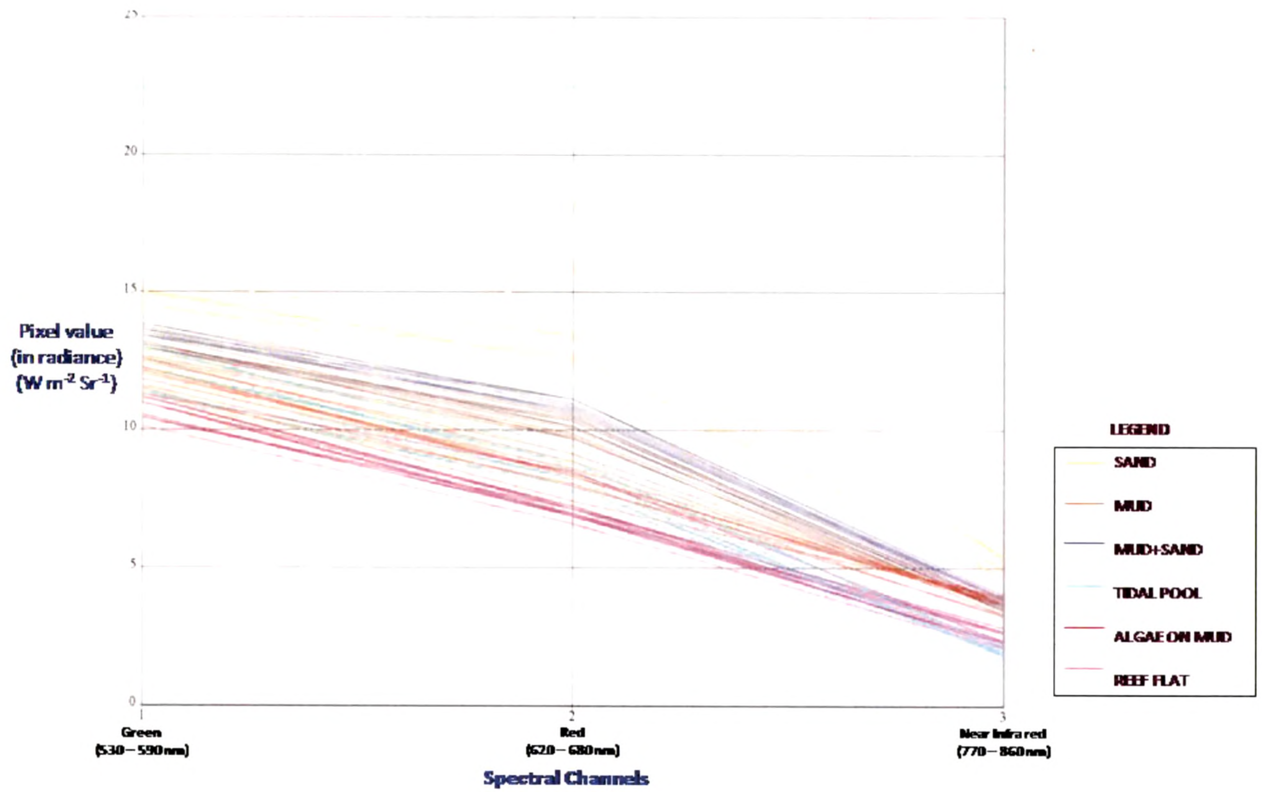


Figure 3.5 IRS P6 LISS IV Classified Images of Sequential Years 2004 to 2007 showing Substrate Occupancy

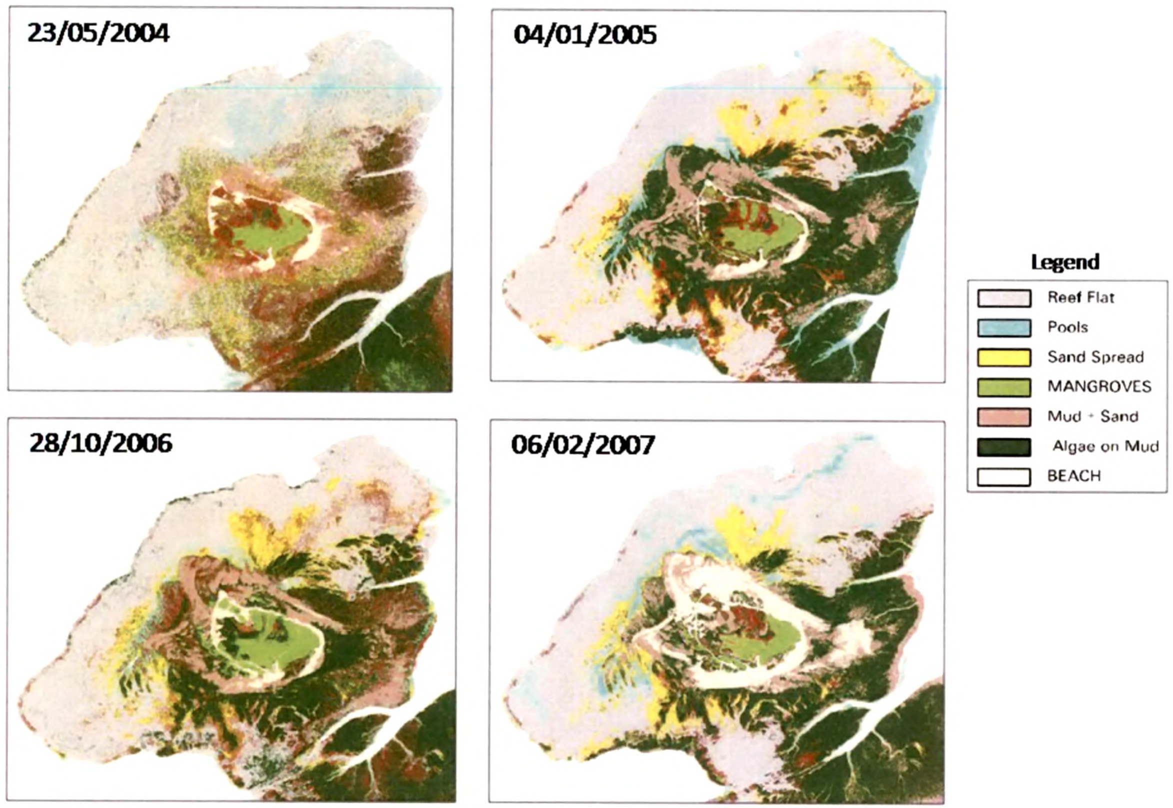


Figure 3.6 Trend of different Substrates over the period 2004-2007

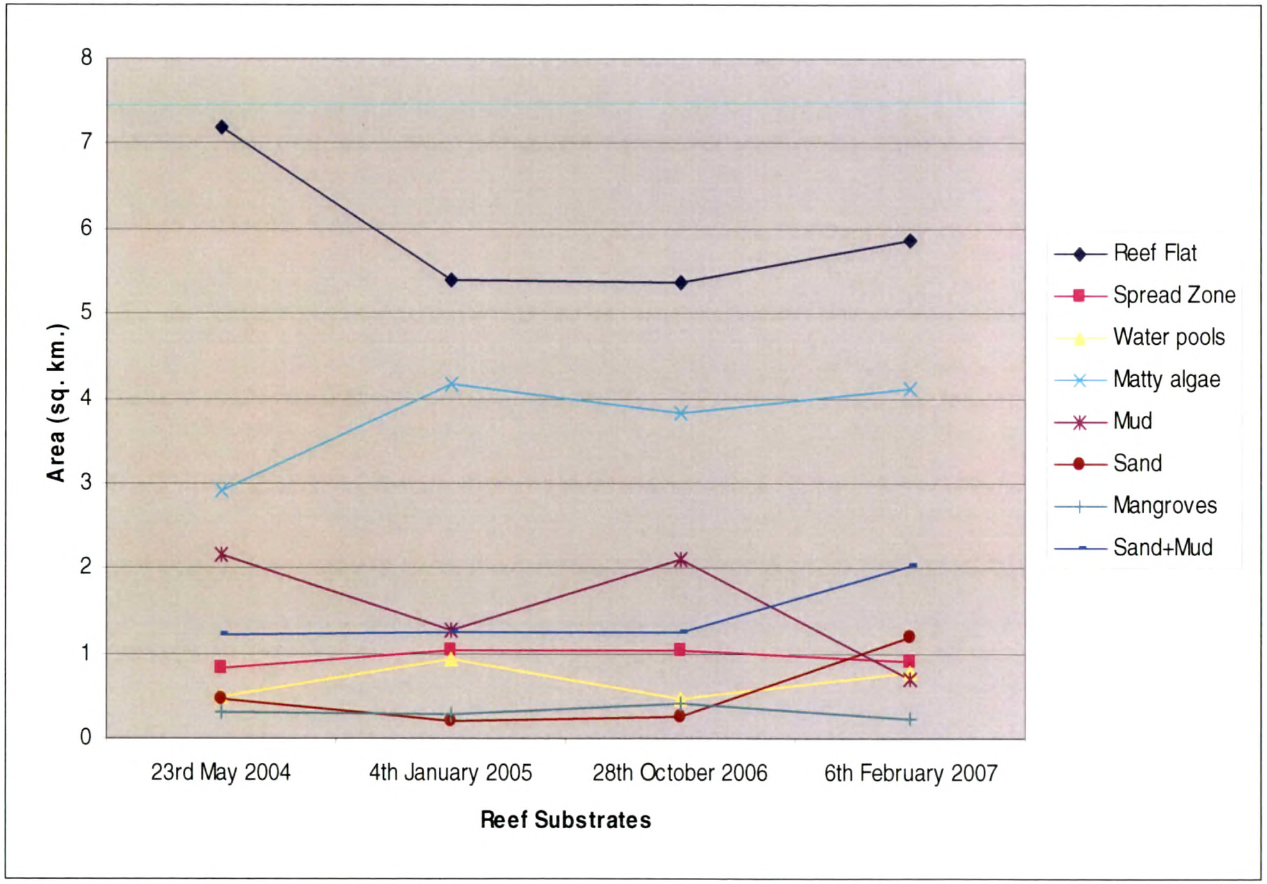
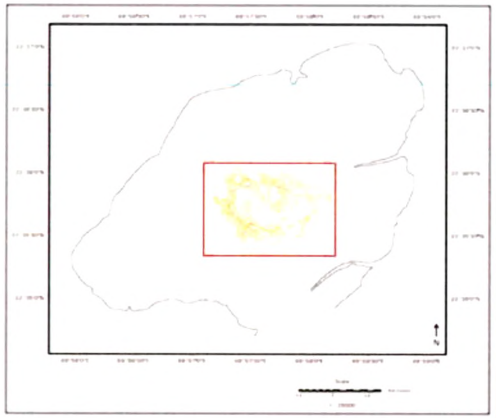


Figure 3.7 Change Detection: Core Region 2004 vs 2005



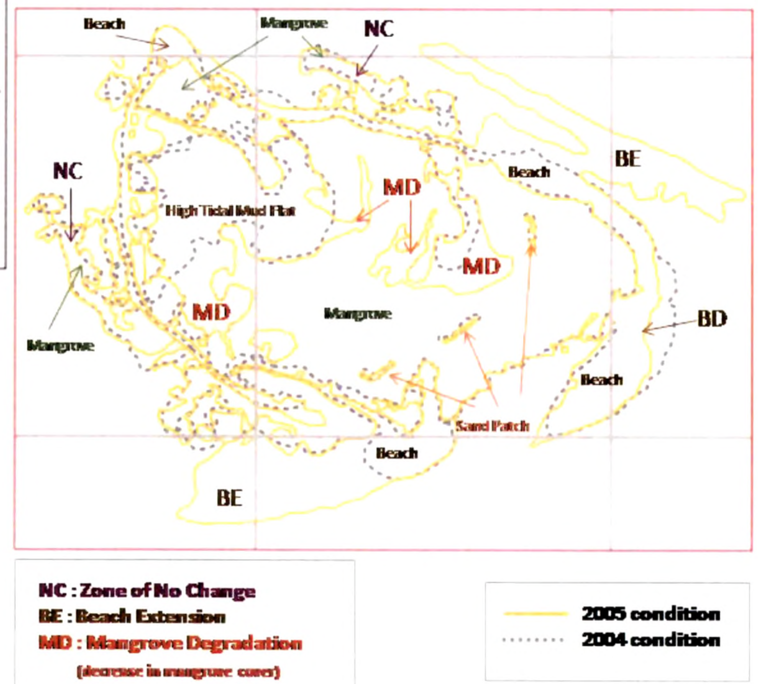


Figure 3.8 Change Detection: Core Region 2005 vs 2006

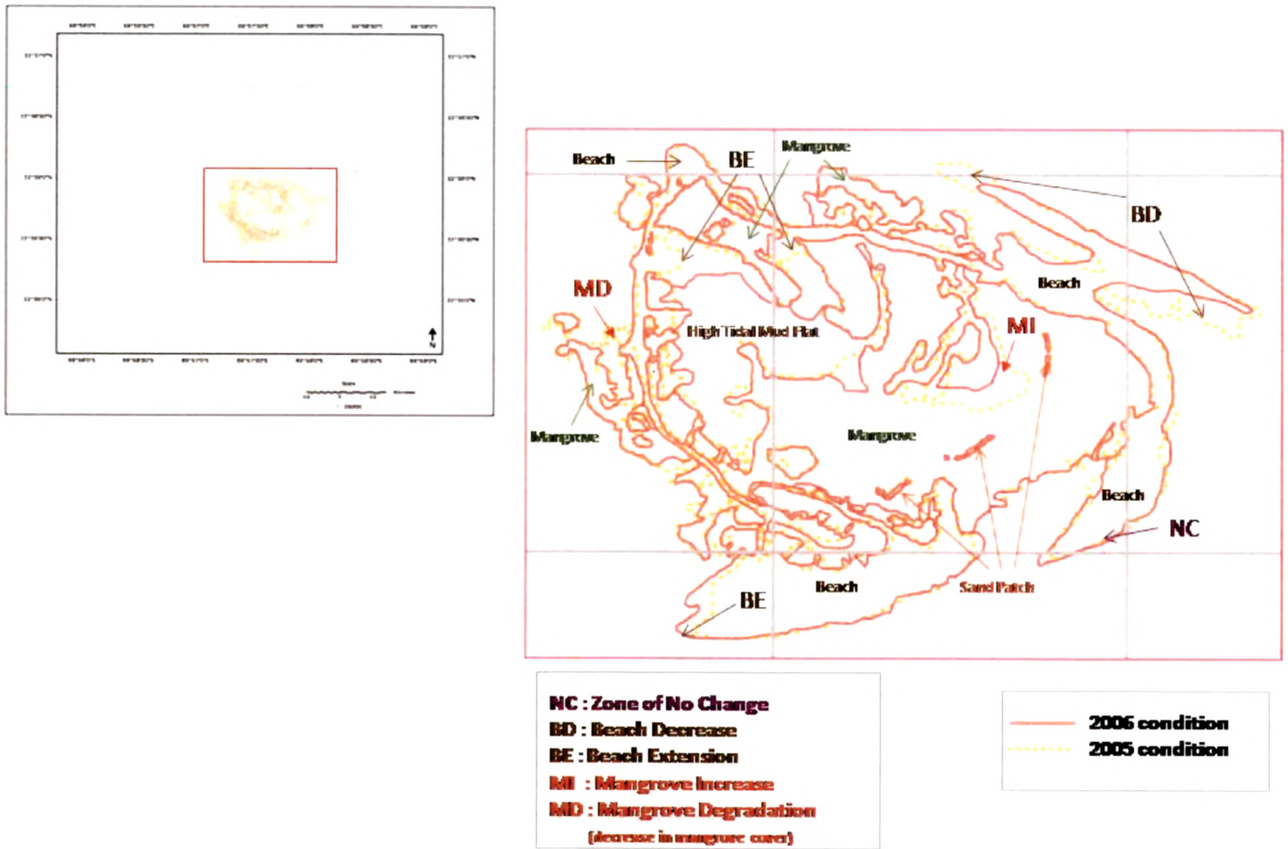


Figure 3.9 Change Detection: Core Region 2006 vs 2007

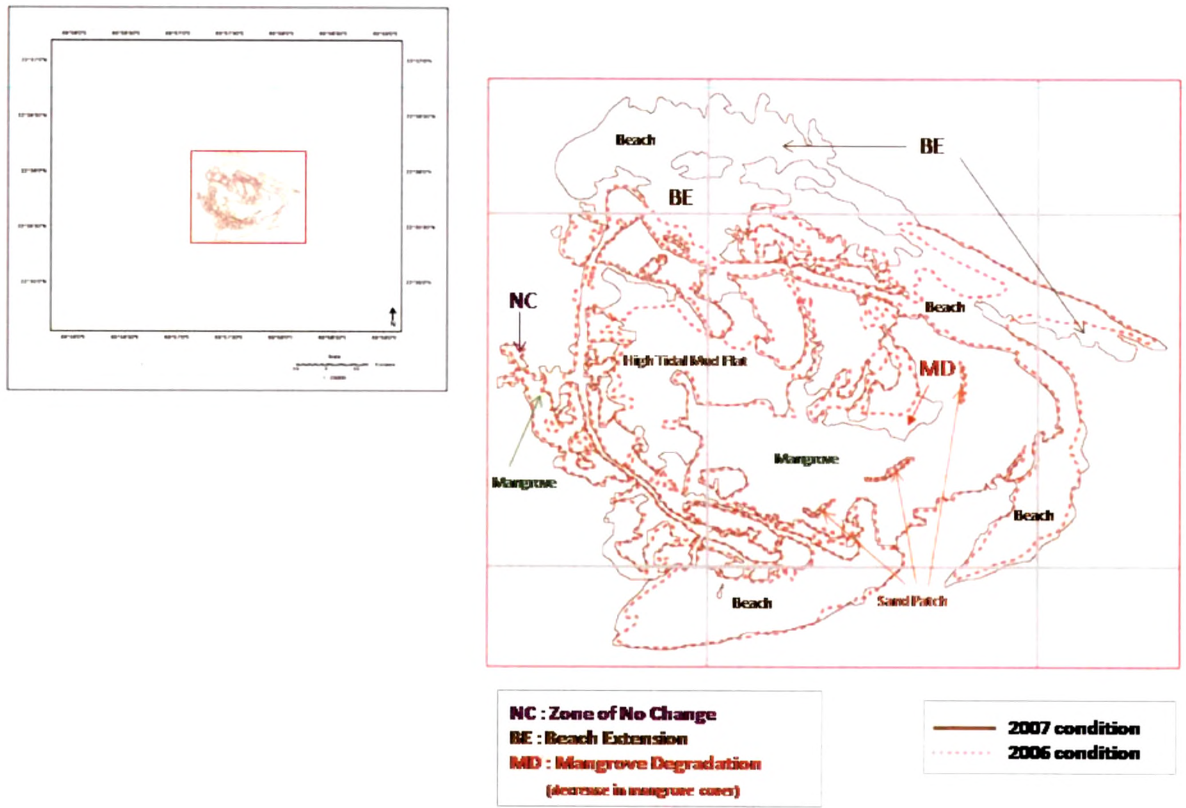


Figure 3.10 Change Detection in Flowline Condition 2004 vs. 2005

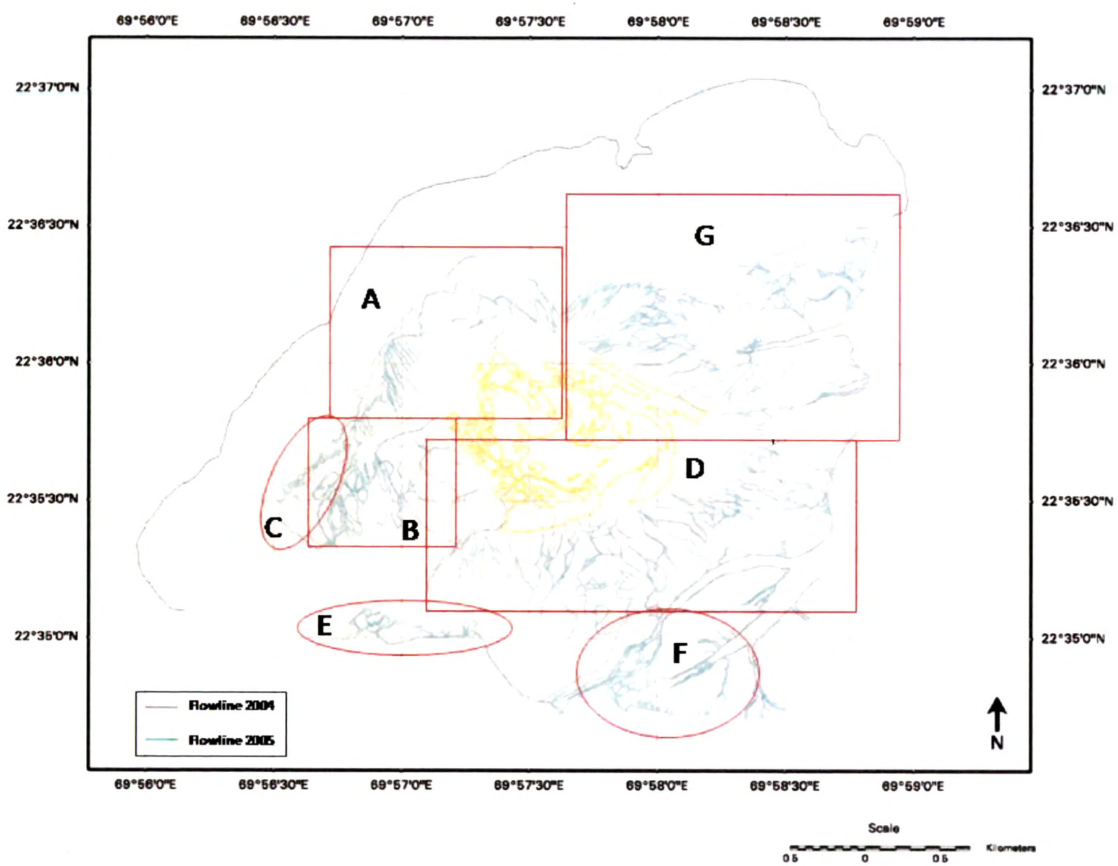


Figure 3.11 Change Detection in Flowline Condition 2005 vs. 2006

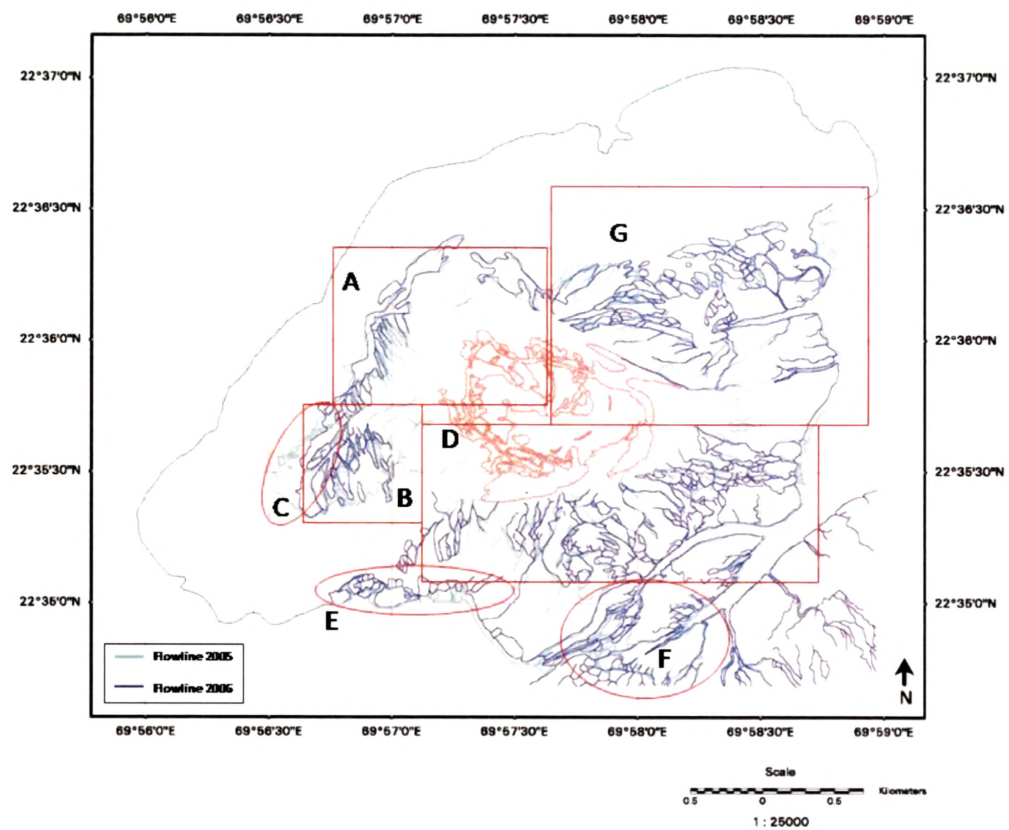


Figure 3.12 Change Detection in Flowline Condition 2006 vs. 2007

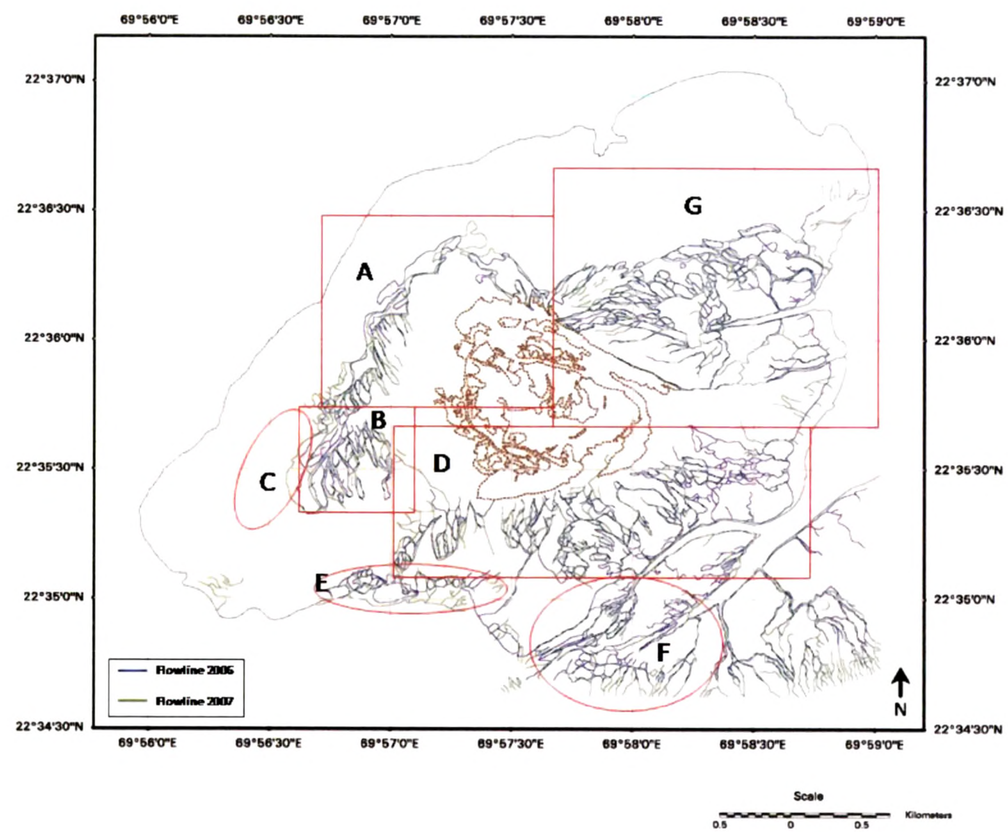


Table 3.3 Summary of change detection of flowlines during 2004-2007

		Statistics			Comparison			
Segment	**Year**	**Principal Flowlines**	**Flowlines segments**	**Inter fluves**	**Complete Overlap**	**Partial Overlap**	**Landward Extension**	**Substrate**
A	**2004**	7	16	14				Sand
	2005	15	10	22	8	4	2	Sand
	2006	13	17	17	10	6	0	Sand
	2007	12	12	23	9	10	0	Sand
B	**2004**	10	11	11				Sand
	2005	5	23	26	3	7	0	Sand
	2006	9	37	30	12	7	0	Sand
	2007	10	39	26	9	11	0	Sand
D	**2004**	13	14	15				Silt
	2005	26	45	60	3	12	0	Silt
	2006	28	128	106	9	19	0	Silt
	2007	25	142	115	7	30	2	Silt
E	**2004**	4	9	10				Silt
	2005	10	20	21	3	2	0	Silt
	2006	12	31	21	15	5	0	Silt
	2007	11	29	26	10	13	0	Silt
F	**2004**	7	6	6				Silt
	2005	12	47	29	2	4	4	Silt
	2006	15	49	42	7	7	6	Silt
	2007	12	46	47	16	8	13	Silt
G	**2004**	15	16	13				Silt
	2005	35	53	74	3	7	0	Silt
	2006	35	60	67	5	19	2	Silt
	2007	38	65	100	5	27	1	Silt

Figure 3.13 Tidal levels at Okha, Kandla and Navlakhi during RESOURCESAT IRS-P6 Pass Time

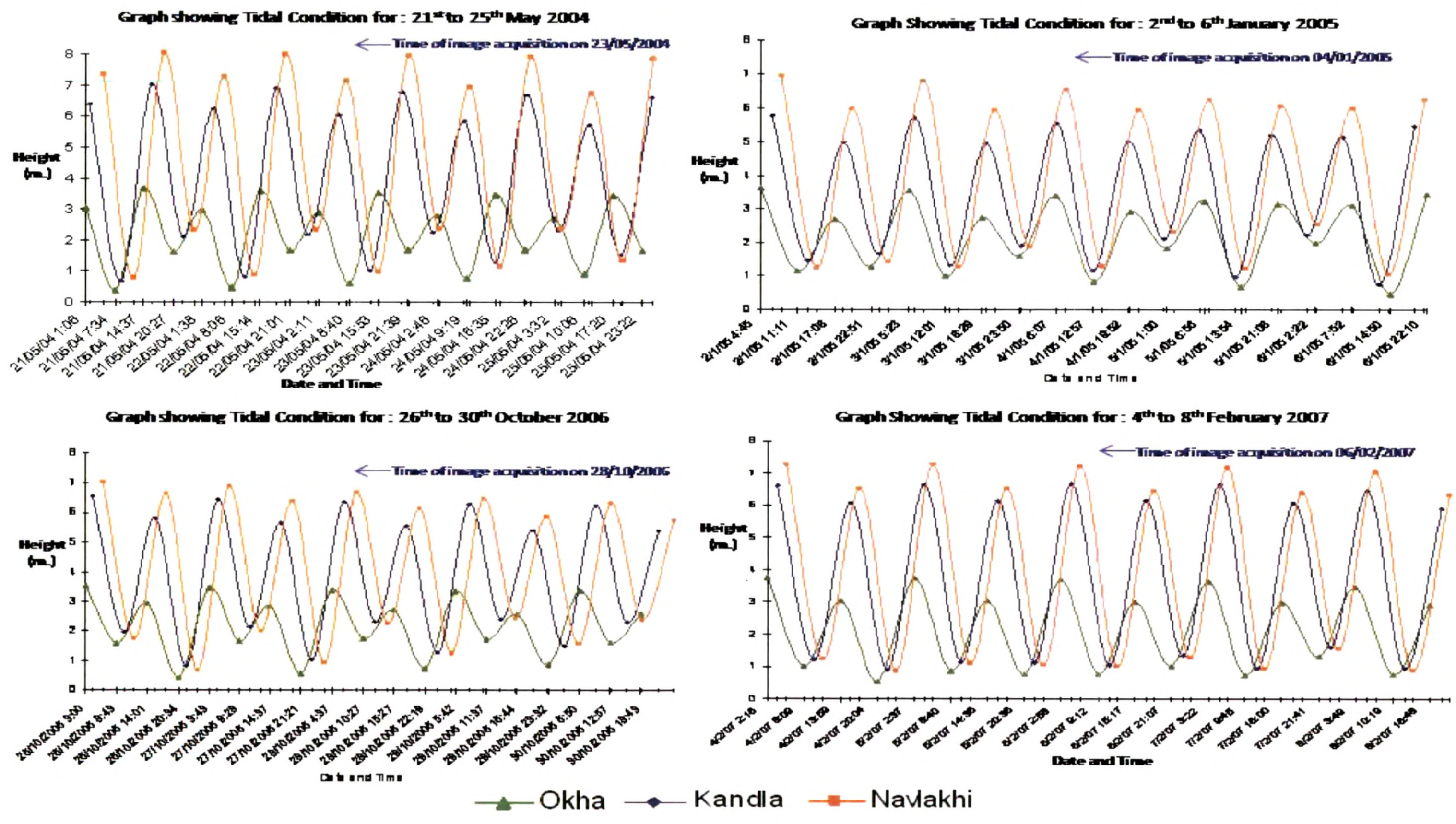
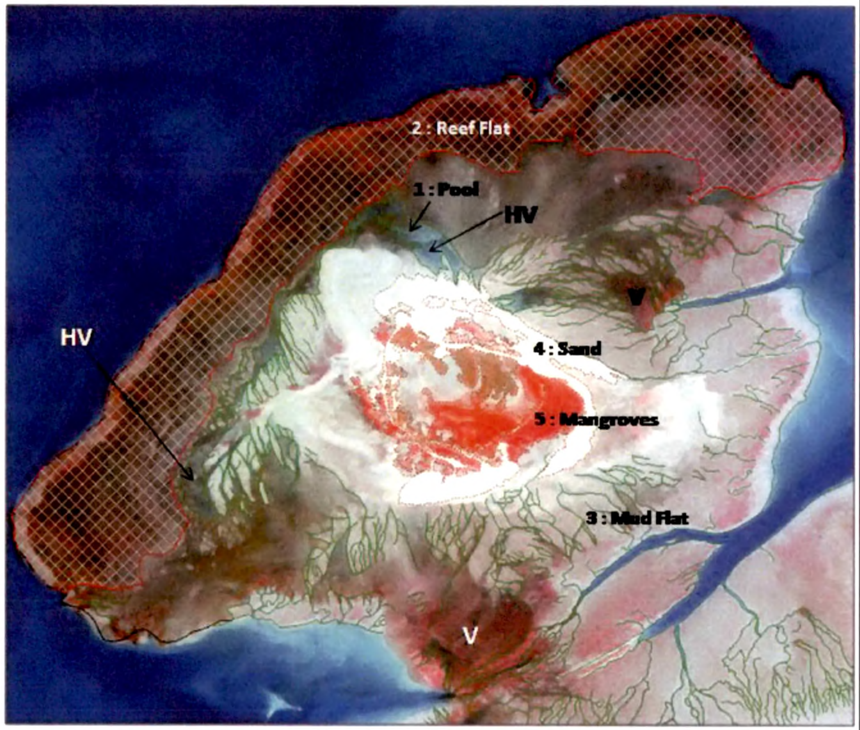


Figure 3.14 Future Scenario of Pirotan Reef



HV : Highly Vulnerable (due to Sand Deposition)

V : Vulnerable (due to Siltation)

: Healthy Reef Region

Organisms found in Different Substrates of Reef

1 : Corals, Bonellia, Sabella, Aplysia, Octopus, Puffer Fish, Reef Gobies

2 : Corals, Sea Anemone, Chiton, Patella, Cypraea, Octopus, Nautilus, Crabs, Brittle Star, Ophioderma, Anthenea (Star Fish), Chelone (Green Sea Turtle), Coral Snake

3 : Neries, Mytilus, Mud Skipper, Crabs, Cerithium, Tibia, Pugilna, Nassa

4 : Crabs, Molluscans

5 : Molluscans, Crabs, Snakes, Birds

Plate 3.1 Ground Photographs of Pirotan Reef