**Introduction**

Remote sensing sensors provide synoptic, repetitive, panchromatic and multispectral bands with radiometric, spectral and spatial resolution in digital formats hence enormously used to study the earth resources.

Benthic vegetation (seagrass and seaweed) can be spatially mapped and monitored worldwide using medium resolution satellites like Landsat, SPOT and Hyperion and IRS LISS III data. In India, efforts were made on mapping seaweeds along the Indian coast using medium and high resolution Indian satellite sensors. However, such studies are restricted to seaweeds associated with corals (Bahuguna et al., 1998; Nayak et al., 2001; Nayak et al., 2003).

Chlorophyta, Phaeophyta and Rhodophyta are three major divisions of the seaweeds. These are distributed in the intertidal region and below in infralittoral region depending on light penetration.

In India, there have been many attempts made to quantify standing stocks of seaweed by several investigators. However, estimates have been varied from investigator to investigator; therefore it is highly essential to use remote sensing technique for monitoring, spatial and temporal distribution study of the seaweed.

In view of the necessity of accurate knowledge of spatial and temporal distribution of seaweeds along the coast of India and available facilities of high-resolution multispectral bands obtained from satellite sensors, it was proposed to correlate the data generated using traditional sampling methods with the data that obtained from satellite sensors

**Objectives**

1. To identify suitable site(s) for the study along the coast of Maharashtra and Gujarat state
2. To select seaweed genera as representatives of the group for further studies
3. To identify ideal spatial resolution and multispectral bands of satellite sensor
4. To record the spatial and temporal distribution of seaweeds by applications of ground data and multispectral bands obtained from satellite sensors.
5. To examine the relationship between seaweeds and environmental factors.
6. To develop a methodology to estimate near accurate biomass of seaweeds using multispectral bands obtained from satellite sensor and ground sampled biomass.
Stephenson and Stephenson (1949) have described the universal patterns of the zonation and distribution of marine organisms between tidemarks, on rocky coasts. However Krishnamurthy (1967) has been described that Indian coasts harbour a predominantly sublittoral algal community with practically no zonation.

Cameron initially did the seaweed survey from the space in 1950, by using aerial photography. Jamison (1972) suggested the potentials of combining traditional ground survey methods with serial remote sensing techniques for the seaweed survey.

**Ground methodology**

The study was carried by selecting four sites along the coast of Maharashtra and Gujarat. Major criteria followed for the choice of sampling sites were vertical extent of the intertidal region and diversity of seaweeds. *Sargassum, Ulva* and *Enteromorpha* were growing abundantly over larger area in Arnala Island, coastal tracks of Palshet and Malvan (Maharashtra) and Kalubhar Island, (Gujarat) hence these sites were selected as study areas.

Ground information about seaweed diversity was collected through periodical visits to study area starting from April 2008 to January, 2011. To record the spatial and temporal distribution of seaweeds by applications of multispectral bands obtained from satellite sensor, *in situ* samplings were carried at time of satellite image acquisition. Line transects and quadrates method was used for filed sampling. The geographical locations of each sampled quadrates were located using Global Positioning System (GPS)

UV-VIS-NIR Laboratory Spectrophotometer was used to measure spectral reflectance of representative thallus samples of each group of seaweeds, such as *Ulva lactuca* and *Sargassum tennerimum* and *Porphyra*.

**Remote sensing methodology**

Satellite images obtained from IRS P6 LISS III & LISS IV have been used. The IRS P6 LISS III & LISS IV with medium and high spatial resolution sensors having four & three multispectral bands respectively. These sensors have green (520-590), Red (620-680) and NIR (760-860) bands with 23.5 and 5.8 m spatial resolutions respectively. Satellite data was procured from National Remote Sensing Centre, (ISRO).

The ERDAS IMGINE 9.1 and ENVI 4.2 softwares were used for image processing and data analysis. After the geometric, radiometric and atmospheric corrections on satellite images, were used for extraction of spectral signatures and classification of habitats on image. To study the spectral behaviour of various
components on image, collected ground sampling points were imported on image and extraction of reflectance values from corresponding pixels.

Supervise and unsupervise classification technique was used for classification of substrate and type of seaweed diversity. After the classification area estimation was done by multiplying the histogram values with resolution (square) of the sensor or by using add area column option in Raster Attribute Editor tool of in ERDAS imagine.

For biomass modeling, linear regressions were employed to establish empirical relationships between the measured seaweed biomass sampling points and the corresponding pixel values from the image. The regression equation was of the type: \( y = mx + c \). Ratio transformed image (NDVI) is used to establish the linear relationship. The obtained equation was then applied to the ratio-transformed image to prepare biomass distribution maps and total biomass estimation using ENVI 4.5 image processing software.

1. **Arnala Island**

Ground sampling of was carried in February, April, May and December, 2009. Information about seaweed diversity in the intertidal zone was collected from 12 line transects placed in 4 sector.

The intertidal region around Arnala Island consists of sandy beaches and mudflats, covered by boulders or pebbles and scattered smaller and larger tide pools. Seaweed growth was confined to tide pools. *Enteromorpha, Ulva, Acanthophora, Gracilaria* and *Laurencia* were dominant seaweed distribute in upper and lower midlittoral zone in the intertidal region. Maximum diversity of seaweed was occurred in February and December. Luxuriant period for their growth was February. Degeneration occurred in April and May.

Spectral reflectance derived from IRS P6 LISS IV sensor implies that spectrally it was not possible to detect the seaweeds in the tide pools, due to turbid water in tide pool. Using supervise classification substrate, vegetation and tide pools in the intertidal region of the Arnala Island can be accurately classified based on their spectral reflectance properties with 86% overall accuracy and Khat= 83.33. Satellite data was used as potential spatial data source for identification of tide pool and area of tide pool in intertidal region. Total area occupied by tide pool was 7.58 hectare. Total maximum (75.45 mt) biomass (wet) computed in February while minimum (25.17 mt) in May.
2. Coastal track of Palshet (Palshet and Velaneshwar)

Ground sampling was carried in January, March, May and December, 2009. Information about seaweed diversity in the intertidal zone was collected from 8 line transects.

*In situ* observations revealed that members of Chlorophyceae, Phaeophyceae and Rhodophyceae distributed in lower mid littoral and infra littoral fringe zone in the intertidal region of coastal track of Palshet. Intertidal algal community in the intertidal region of the coastal track of Palshet was with practically no zonation and the pattern of seaweed distribution was mosaic type. Maximum diversity and growth of seaweed was reported in December. *Sargassum* was dominant along with *Padina, Dictyota* and *Spathoglossum*.

Seaweeds grown over rocky substrates showed characteristic spectral behaviour in green band (520 -590 nm), red (620 to 680 nm) and NIR (760-860 nm) bands of LISS IV sensor. A significant reflectance difference was observed between brown seaweed and bare rock in the green (1%), red (2%) and NIR (more than 2%) band. It was not possible to map seaweed in the infra littoral fringe and infra littoral zone because this zone was under submerged condition and under continuous influence of wave action at the time of image acquisition. Using unsupervise classification seaweed and substrate in the intertidal region was classified well using IRS P6 LISS IV data, with overall classification accuracy 85% and Khat= 0.83. Brown seaweed located in midlittoral zone was identical on satellite image. Area occupied by brown seaweed was 40 hectare in December and 24 hectare in March. Strong Linear relationship was obtained between ground sampled biomass and NDVI (LISS IV) image ($r^2=0.82$, $P<0.005$). Using satellite image total estimated biomass (Wet) over 40 hectare area (occupied by seaweed) in intertidal region was 972 mt with minimum error (RMSE= 576g/m$^2$) in December.

3. Malvan Fort and Arsemahal

Ground sampling was carried in January, May and December, 2009. Information about seaweed diversity in the intertidal zone was collected from 8 line transects.

Members of Chlorophyceae were located in upper and lower mid littoral zone. Members of Phaeophyceae and Rhodophyceae were distributed in upper and lower mid littoral and infralittoral zone around Malvan Fort and Arsemahal. *Sargassum* was dominant seaweed along with *Padina, Dictyota, Spathoglossum* and *Sphacelaria* distributed in lower mid littoral zone and infralittoral zone.
Seawater at sites was optically clear and shallow intertidal region which permit light upto varying depths hence luxuriant growths *Sargassum* was observed in infralittoral. *Sargassum* was attached to rock or any hard substrate (corals and boulders) in infralittoral zone and was seen floating in water.

Using satellite image emerged and floating *Sargassum* was spectrally identified. Using unsupervise classification method overall classification accuracy was 85 % (Khat= 0.83) for emerged and floating seaweed. Area obtained from unsupervise classification was 162 hectare. At the time of image acquisition seaweed was under emerged and submerged condition at time of image acquisition. Therefore, NDVI values for the seaweed was negative and do not show any relationship with biomass. Hence, satellite was used as spatial data source. The total biomass estimated was 2112.48 mt (Wet) in January. *Sargassum* forms the major component of biomass in December and January.

4. Kalubhar reef

Ground sampling was carried in January, April and December (2009-2011). Information about seaweed diversity in the intertidal zone was collected from 12 line transects placed in 4 sectors.

Seaweeds was growing on mud, sand, degraded reef, live and dead coral. In the intertidal region of Kalubhar reef, maximum diversity of members of Chlorophyceae was noted in January while maximum diversity of members of Phaeophyceae and Rhodophyceae in February. Luxuriant period of seaweed growth was February and degeneration occurred in April. Maximum seaweed diversity occurred in algal ridge zone. *Sargassum* was dominant seaweed in February which growing in algal ridge zone.

Using LISSIII and LISS IV data, seaweed on sand, mud, and coral were spectrally discriminated. Using supervise classification method seaweed distributed on various substrate were classified well but spectral mixing was occurred between spectrally similar feature. After contextual editing overall classification accuracy was 86% (February), 90% (April), 87% (January) and 86% (May).

Strong linear relationship was obtained between ground sampled biomass and NDVI ($r^2 = 0.67$, $r^2=0.88$, and $r^2=0.70$, p << 0.005). Using satellite image total estimated wet biomass over 1034 hectare area was 31,247.48 mt (wet) in February, 19,302.50 mt wet) over 875 hectare in January and 9, 309 mt (wet) in April over 1223 hectare area.
Conclusions

Results of the present conclude that satellite images are potential data source for monitoring, mapping and biomass estimation of intertidal seaweed. Using LISSIII and LISSIV data it was possible to differentiate between green and brown seaweed based on their spectral signatures. Using multispectral bands of satellite sensors discriminate seaweed from different substrate. Maximum difference in reflectance values between seaweed and substrate noted in red band. Unsupervise classification method was found suitable for the classification seaweed. Maximum classification accuracy in seaweed mapping can be achieved by selection of low tide satellite image, collection of maximum ground control points and selection of proper classification method. Spectral and temporal resolutions of sensors can be potentially used for seasonal and temporal study of seaweed. The biomass difference between ground measured and satellite estimated showed minimum error, indicates that the satellite remote sensing can be used as advance tool to estimate biomass and distribution information of seaweed resources grown over larger area.

In optically clear water sensors are able to identify floating and submerged seaweed at some extent while multispectral sensors fail to detect seaweed growing in turbid water due to scattering of light by sediments in water. Therefore, mapping of seaweed submerged and turbid water it is necessary to use hyperspectral remote sensing data.