Present and future of marine production in Boka Kotorska

First results from satellite remote sensing for the breeding areas of filter feeders in the Bay of Kotor
INTRODUCTION

Environmental monitoring is one of the ways to verify the evolution of an ecosystem, and studying the biodiversity that typifies it is the basis to study its possible changes over time. Assessing the effects on organisms and environments of the many anthropic activities is extremely important to ensure proper management and preservation of natural resources. In the last decades the choice of methods for environmental quality assessment aimed in particular to the study of those biological components of the ecosystem that are able to respond, with various sensitivities, to the changes of the environment. Remotely sensed images are an essential instrument for this purpose since their informative features can make a meaningful contribution to the study of the evolution or regression of the ecosystem itself.
30 images were acquired in total, but the ones from Landsat 5 TM were selected since Landsat 7 ETM+ images show gaps due to a sensor failure in 2003.

18 images from Landsat5 TM and 12 images from Landsat7 ETM+ were downloaded.
7 images were selected among all from Landsat 5 TM considering the coverage of the area of study, clouds and season (date) of acquisition:

<table>
<thead>
<tr>
<th>low tide</th>
<th>high tide</th>
<th>date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat 5</td>
<td>Landsat 5</td>
<td>01/09/1984</td>
</tr>
<tr>
<td>Landsat 5</td>
<td>Landsat 5</td>
<td>04/07/2003</td>
</tr>
<tr>
<td>Landsat 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landsat 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landsat 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landsat 5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Another factor that has to be considered when analysing images for an inshore, shallow water area is the tide phase. The confrontation between different years should be made for similar conditions, both of season and tide.
The low tide satellite images were captured at 9.17 AM.
COLOR COMPOSITE 3-2-1

Example of RGB color composite from bands 3-2-1 (red-green-blue): true color composite, it is like a photograph and enhances submerged areas and smoke columns
Example of RGB color composite from bands 4-3-2 (NIR-red-green): it is similar to photos taken with an infrared camera. The vegetation appears red, urban areas are blue. The shoreline is well defined and water is well distinguished from land, although it is possible to define some partially submerged structures.
COLOR COMPOSITE 4-5-3

Example of RGB color composite from bands 4-5-3 (NIR-SWIR-red): The water-land boundary is very clear, humid terrains are darker.
Example of RGB color composite from bands 7-4-2 (SWIR-NIR-green): Algae appear in a light-blue color, conifer trees are darker than deciduous plants, water is dark blue, vegetation is green and urban or plant-free areas appear pink.
Example of RGB color composite from bands 6-2-1 (TIR-green-blue): This color composite shows very well the differences in temperature within the water body. This composite required a masking for the land area to enhance the difference in temperature.
Example of RGB color composite from bands 7-2-1 (SWIR-green-blue): This composite is very useful for oil spills detection. The anomaly, if present, would take on a red color on a dark background.
The **unsupervised classification** is a preliminary analysis that is performed on images when you have little or no information of what the image really shows.

- UC is used to cluster pixels in a dataset based on **statistics only**, without any user-defined training classes. The unsupervised classification techniques available are ISODATA and K-Means.

- **K-Means** UC calculates initial class means evenly distributed in the data space then iteratively clusters the pixels into the nearest class using a **minimum distance** technique. Each iteration recalculates class means and reclassifies pixels with respect to the new means. All pixels are classified to the nearest class unless a standard deviation or distance threshold is specified, in which case some pixels may be unclassified if they do not meet the selection criteria. This process continues until the number of pixels in each class changes by less than the selected pixel change threshold or the maximum number of iterations is reached.
For the unsupervised classification, bands 1,2,3 and 4 were used, since:

- **Band 1**: Blue light (400-500 nm) is scattered by the atmosphere and illuminates material in shadows better than longer wavelengths. Blue penetrates clear water better than other colors. It is absorbed by chlorophyll, and so plants don't show up very brightly in this band. However, it is useful for soil/vegetation discrimination, forest type mapping, and identifying man-made features.

- **Band 2**: Green light (500-600 nm) penetrates clear water fairly well, and gives excellent contrast between clear and turbid (muddy) water. It helps find oil on the surface of water, and vegetation (plant life) reflects more green light than any other visible color. Manmade features are still visible.

- **Band 3**: Red light (600-700 nm) has limited water penetration. It reflects well from dead foliage, but not well from live foliage with chlorophyll. It is useful for identifying vegetation types, soils, and urban (city and town) features.

- **Band 4**: Near IR (NIR, 700-1200 nm, redder than red, but not visible) is good for mapping shorelines and biomass content. It is very good at detecting and analyzing vegetation.
IMAGE CLASSIFICATION – RESULTS

July 24, 1987

July 23, 2010

August 9, 1987

August 24, 2010
MASKED IMAGE CLASSIFICATION – RESULTS

July 24, 1987

July 23, 2010

August 9, 1987

August 24, 2010
PRINCIPAL COMPONENTS ANALYSIS (PCA)

When studying water depth and bottom structures, Principal Components Analysis (PCA), of the visible bands of TM, has been shown to be a significant support to other classifiers. Of the many algorithms discussed in the literature, for determining bathymetric properties from Landsat TM data, PCA appears to be the best alternative when in situ field measurements were not performed during sensor overpass.

PCA is a statistical technique that transforms a multivariate data set consisting of inter-correlated variables into a data set consisting of variables that are uncorrelated linear combinations of the original variables.

For remote sensing investigations, principal component transformation is based on the analysis of the relationship between the different bands; the rotation of the axes produces a set of image bands, uncorrelated with each other.

- Band 1 and Band 2 were used in a PCA for this research
- The first component (PC1) contained the variance related to water depth
- The second component (PC2), orthogonal to the first, contained the variance associated with bottom structure
PCA RESULTS - PRINCIPAL COMPONENT 1

July 24, 1987

July 23, 2010

August 9, 1987

August 24, 2010
PCA RESULTS - PRINCIPAL COMPONENT 2

July 24, 1987

July 23, 2010

August 9, 1987

August 24, 2010
PCA 1, PCA 2 AND BAND 3 - RESULTS

The two PCAs were then combined in a hybrid routine, with TM3, to yield a shallow water environment classification.
IMAGE ANALYSIS – BAND RATIO

- A satellite image gives a great number of potential data
- While studying a sea water body, a few factors that are important are:
  - dissolved oxygen
  - BOD (biological oxygen demand)
  - pH
  - Salinity
  - Chlorophyll
  - Turbidity
  - Fluorescence
  - Water temperature
  - Redox potential and organic matter in sediment
- Some of this parameters were studied with a band ratioing approach on the images and several indexes were calculated, so that a relative difference in intensity of a certain value is highlighted

Dessi et Al., 2008 - MODIS data processing for coastal and marine environment monitoring : a study on anomaly detection and evolution in Gulf of Cagliari (Sardinia – Italy)
• Oily substances generally have greater reflectance in relation to the marine water, especially in the blue spectral range: this is due to fluorescence induced by $\lambda<400$ nm sunlight rays.

• A relative fluorescence index ($F$) was developed. 
  \[
  F = \frac{\text{Blue} - \text{Red}}{\text{Blue} + \text{Red}} = \frac{B1 - B3}{B1 + B3}
  \]

• The algorithm is based on the relationship between blue and red ranges (respectively bands 3 and 1 in Landsat data) in which the higher is the value of the contribution of blue and the greater is $F$.

• The elaboration allows a better enhancement of the anomalies in relation to a simple true color composite, and the higher values of $F$ index may let presume that the anomaly substance has hydrocarbon components.
FLUORESCENCE INDEX

July 24, 1987 - Fluorescence Index
Band 1 and Band 3

Legend
Value
High: 0.8706049
Low: 0.20887

August 9, 1987 - Fluorescence Index
Band 1 and Band 3

Legend
Value
High: 0.695652
Low: 0.202308

July 23, 2010 - Fluorescence Index
Band 1 and Band 3

Legend
Value
High: 0.654211
Low: 0.195718

August 24, 2010 - Fluorescence Index
Band 1 and Band 3

Legend
Value
High: 0.699553
Low: 0.202128
CHLOROPHYLL INDEX

• Eutrophication of water bodies can be quantified in term of concentration of chlorophyll contained in the algal plankton cells. Chlorophyll is one of the photosynthetic agents, contributing to the color of water. A large volume of literature exists on using remote sensing for mapping chlorophyll $a$, an indicator of algal concentration and a key parameter for assessment of water quality.

• Knowledge about the amount of phytoplankton has important implications for primary production and carbon cycle models as well as for monitoring the state of water bodies.

• Most remote sensing studies of chlorophyll in water are based on empirical relationship between radiance in narrow bands or bands ratio and chlorophyll concentration.

• Techniques used were band rationing where the ratios were found the most effective in estimating chlorophyll $a$.

• A relative chlorophyll index ($C$) was developed.  
  \[ C = \frac{\text{Blue}}{\text{Red}} = \frac{B1}{B3} \]

  Usali et Al., 2008 – *Use of remote sensing and GIS in monitoring water quality*
CHLOROPHYLL INDEX

July 24, 1987 - Chlorophyll Index
Band 1 and Band 3

Legend
Value
High: 15.4
Low: 1.70356

July 23, 2010 - Chlorophyll Index
Band 1 and Band 3

Legend
Value
High: 5.03333
Low: 1.37656

August 9, 1987 - Chlorophyll Index
Band 1 and Band 3

Legend
Value
High: 5.57143
Low: 1.82660

August 24, 2010 - Chlorophyll Index
Band 1 and Band 3

Legend
Value
High: 5.65036
Low: 1.30667
TURBIDITY INDEX

- Water turbidity is an expression of the optical properties of water, which cause the light to be scattered and absorbed rather than transmitted in straight lines. It is therefore commonly regarded as the opposite of clarity. As water turbidity is mainly caused by the presence of suspended matter, turbidity measurement has often been used to calculate fluvial suspended sediment concentrations.
- The best correlation of turbidity of reflectance was red reflectance.
- Other studies have been conducted in turbidity mapping; it was found that Landsat 5 TM Band 3/Band 2, Band 4/Band 3 are good for predicting turbidity. Since what we are dealing with here is not a lake but a semi-closed marine basin, we investigated on the effectiveness of both indexes.
- Two relative turbidity indexes (T) were developed.
  - TRG = Red/Green = B3/B2
  - TIR = Near Infrared / Red = B4/B3

Usali et Al., 2008 – Use of remote sensing and GIS in monitoring water quality
TURBIDITY INDEX - 1

July 24, 1987 - Turbidity Index
Band 2 and Band 3

Legend
Value
High: 2.25
Low: 0.208333

July 23, 2010 - Turbidity Index
Band 2 and Band 3

Legend
Value
High: 1.23556
Low: 0.985217

August 9, 1987 - Turbidity Index
Band 2 and Band 3

Legend
Value
High: 1.15
Low: 0.529412

August 24, 2010 - Turbidity Index
Band 2 and Band 3

Legend
Value
High: 1.23913
Low: 0.5
TURBIDITY INDEX - 2

July 24, 1987 - Turbidity Index
Band 3 and Band 4

Legend
Value
High: 2.6
Low: 0.473654

July 23, 2010 - Turbidity Index
Band 3 and Band 4

Legend
Value
High: 2.657746
Low: 0.407407

August 9, 1987 - Turbidity Index
Band 3 and Band 4

Legend
Value
High: 2.420657
Low: 0.5

August 24, 2010 - Turbidity Index
Band 3 and Band 4

Legend
Value
High: 2.530582
Low: 0.322581
WATER TEMPERATURE

Digital numbers associated to each pixel that builds the image are converted into spectral radiance using the following equation (Markham and Barker, 1986):

\[ L_\lambda = 0.0056322 \times DN + 0.1238 \]

Spectral radiances are then converted into satellite brightness temperature using the following relationship that is similar to the Planck equation with two free parameters (Schott and Volchok, 1985; Wukelic et al., 1989):

\[ T_B = \frac{K_2}{\ln \left( \frac{K_1}{L} + 1 \right)} \]

where \( L \) is the blackbody radiance for a temperature, \( T_B \), integrated over band 6, and \( K1 \) and \( K2 \) are two free parameters with the values of \( K1 = 60.776 \text{ mWcm}^{-2}\text{sr}^{-1}\text{μm}^{-1} \) and \( K2 = 1260.56 \text{ K} \).
WATER TEMPERATURE

July 24, 1987 - Surface Temperature

July 23, 2010 - Surface Temperature

August 9, 1987 – Surface Temperature

August 24, 2010 – Surface Temperature
CONCLUSION

• The importance and complexity of the marine environment requires a continuous multidisciplinary study

• A limitation of a satellite data monitoring system is given by meteorological conditions, as cloud cover may prevent radiance penetration from sea surface

• When using satellite imagery for environmental studies it is important to consider spatial and spectral resolution

• A proper validation of the procedure and of the results should be done by direct on-ground measurements