

# Seagrass mapping and monitoring along the coast of Crete, Greece

Based on author's MSc thesis presentation  
originally held at Enschede, Netherlands (2011)

Presented at a job interview for the  
Research Training Group (RTG) Baltic TRANSCOAST.  
topic 'B1: Impact of nutrient emissions from land on communities of macrophytes'

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October 8-9, 2015

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# List of Acronyms

<b>ANOVA</b>	Analysis of Variance	11
<b>BRDF</b>	Bidirectional Reflectance Distribution Function	38
<b>CDOM</b>	Colored Dissolved Organic Matter	37
<b>CZCS</b>	Coastal Zone Colour Scanner	40
<b>GEF</b>	Global Environment Facility	13
<b>GIS</b>	Geographic Information System	34
<b>GPS</b>	Global Positioning System	14
<b>Gretl</b>	Gnu Regression, Econometrics and Time-series Library	43
<b>HCMR</b>	Hellenic Centre for Marine Research	47
<b>Landsat TM</b>	Landsat Thematic Mapper	18
<b>MERIS</b>	Medium-Spectral Resolution, Imaging Spectrometer	55
<b>MODIS</b>	Moderate Resolution Imaging Spectroradiometer	40
<b>RS</b>	Remote Sensing	14
<b>RTM</b>	Radiative Transfer Model	8
<b>SCUBA</b>	Self-Contained Underwater Breathing Apparatus	14
<b>SeaWiFS</b>	Sea-Viewing Wide Field-of-View Sensor	40
<b>SPSS</b>	Statistical Package for the Social Sciences	11
<b>Trios-RAMSES</b>	Hyperspectral Radiance and Irradiance Sensors for the UV, VIS or UV/VIS range	16
<b>UNEP</b>	United Nations Environment Programme	13
<b>VIS</b>	Visible Spectrum	48
<b>WASI</b>	Water Color Simulator	8

## Seagrasses

- a unique group of aquatic plants growing submerged in the sea water
- play vital role in the marine ecosystems of the world Ocean (e.g. basis of the food web)
- create unique, complex, extremely diversified and productive ecosystems in the littoral coastal zones (0-50 meters) all over the world

## Distribution

Globally, there are 58 recognized and described seagrass species

## Examples

Case Study: In this work we focused on seagrass *Posidonia oceanica* (*P. oceanica*), an endemic species of the Mediterranean Sea. The purpose of current study was to apply methods of remote sensing for mapping of seagrass *P. oceanica*.

## Actuality

More than 50% of the world population lives within one km of the coast, which results in continued anthropogenic pressure on the coastal regions. Mapping and environmental assessment of coastal resources become increasingly important nowadays and is necessary for monitoring of the shelf zones

## Significance

This research is a contribution to the development of the methodology of seagrass mapping which aims on the environmental monitoring.

## Posidonia oceanica

The case study of this work is *P. oceanica* seagrass, an endemic Mediterranean seagrass species, dominating in marine landscapes and ecosystems along the coasts of Crete Island.

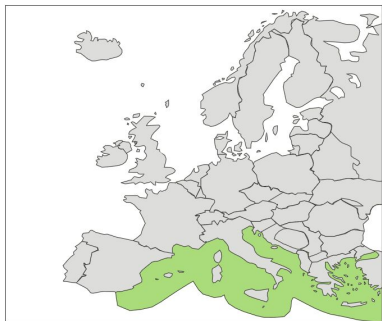


## Physiology

*P. oceanica* consists of long, 5-12 mm broad, hairy-like leaves, 3-4 mm thick roots and short rhizomes (0.5-2.0 mm). Leaves' length: 20-40 cm, in some cases reach up to 1 m.

## Productivity

Growing *P. oceanica* make meadows which consist of smaller patches: matte. *P. oceanica* creates one of the most productive Mediterranean ecosystems. It serves as a biological indicator for assessment of water quality and environment.



- *P. oceanica* is an endemic species of the Mediterranean Sea
  - Main species in the marine coastal environment of Greece
  - *P. oceanica* creates dominant and most productive coastal ecosystem of the Mediterranean Sea
- ↩ Distribution of *P. oceanica* is limited by the western part of the Mediterranean Sea, where cold Atlantic waters enter Gibraltar (as on picture)

## Research Goal

The main goal of this study is to analyze optical properties of the seagrass *P. oceanica* and other seafloor types (carbonate sand), and to apply remote sensing techniques for seagrass mapping in the selected locations of northern Crete

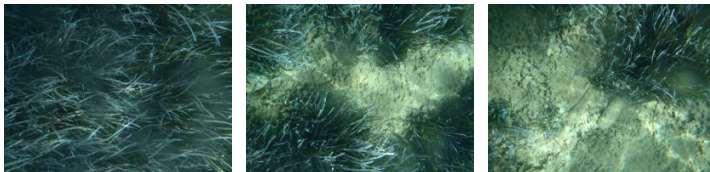
## General Objectives

- Analyzing spectral reflectance of the *P. oceanica* and other seafloor cover types by means of tools Radiative Transfer Model (RTM) using Water Color Simulator (WASI)
- Mapping spatial distribution of the seagrass *P. oceanica* over selected locations along the northern coasts of Crete Island



- 1 To study narrow-band spectral reflectance properties of *P. oceanica* and other seafloor cover types (sand and silt) using WASI water colour simulation software
- 2 To use methods of the in-situ diving observations and underwater videometric measurements by Olympus ST camera in order to receive large-scale imagery of the *P. oceanica* mattes
- 3 To apply remote sensing data (Google Earth aerial images, Landsat scenes) for the monitoring of the seagrass meadows distribution
- 4 To perform images classification for the mapping of the *P. oceanica* distribution along the selected locations over the coasts of northern Crete.

- Is *P. oceanica* spectrally distinct from carbonate sand with varying in-situ conditions ?
- Do broadband and hyperspectral sensors provide enough radiometric information for spectral discrimination of seagrass, and therefore, can be used for mapping of *P. oceanica* ?



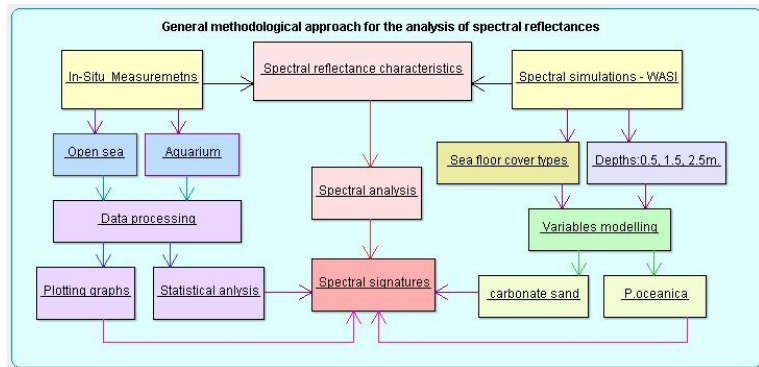
## Hypothesis $H_0$

For the Research Question 1 the Hypothesis  $H_0$  claims: seagrass types are not spectrally distinct from other seafloor types with varying in-situ conditions, which means  $H_0: \mu_1 = \mu_2 = \mu_3 \dots = \mu_n$  The alternative Hypothesis  $H_a$  claims the opposite statement: seagrass is spectrally distinct with varying in-situ conditions,  $H_0: \mu_1 \neq \mu_2 \neq \mu_3 \dots \neq \mu_n$

## SPSS

Statistical Package for the Social Sciences (**SPSS**) statistical analysis and hypothesis testing: Analysis of Variance (**ANOVA**) one-way analysis: results of the single factor (depth) testing of spectral reflectance of *P. oceanica* at various depths: 0.5, 1.5 and 2.5 m. P more than .05, which means that there is a significant difference in radiance of *P. oceanica* at three different depth (0.5, 1.5 and 2.5).

Source of Variation	SS	df	MS	F	P value	F crit
Between Groups	373841.7048	2	186920.8524	407.85359	1.11677	3.01153
Within Groups	261233.1668	570	458.3038014			
Total	635074.8716	572				



The methodology of the current work was guided by various reports and guidelines published by scientific organization focusing on seagrass research, such as following.

- Global-scaled: Global Seagrass Monitoring Network and the World Seagrass Association
- The World Atlas of Seagrasses is published by the United Nations Environment Programme (**UNEP**)
- Australian Seagrasswatch
- European: the Mediterranean association Seagrass-2000, the Mediterranean Institute for Advanced Studies and Seagrasses.org
- US American seagrass recovery campaign by the Seagrassgrow, Seagrass Ecosystems Research Laboratory
- US South Florida: Seagrass.LI and Florida Seagrass organization
- Asian: **UNEP**/Global Environment Facility (**GEF**) South China Sea Project, Marine Conservation Cambodia and Sosmalaysia.org

# Remote Sensing for Seagrass Mapping

Various methods and approaches of the Remote Sensing (**RS**) were applied for studies of seagrass *P. oceanica*, based on following data:

- aerial Google Earth photographs
- iPAQ data and Global Positioning System (**GPS**) records
- non-destructive Self-Contained Underwater Breathing Apparatus (**SCUBA**) based fieldwork sampling and seagrass observations
- videometric footage by means of Olympus waterproof camera
- multispectral imagery

Remote sensing techniques offer clear advantages for seagrass monitoring due to their following characteristics:

- weather-independence
- cost-effectiveness
- accuracy
- spatial coverage

This enable periodic monitoring of the seagrass meadows and gives access to the distant and unapproachable areas.

# Measuring Optical Properties of the Benthic Vegetation

- The optical properties of the sea water vary with different environmental conditions
- Optical properties (e.g. spectral reflectance, radiance, irradiance) reflect current chemical content and physical specifics of the water
- Shallow waters generally contain more dissolved substances and suspended particles
- **RTM** are used for simulation and study of optical properties
- In current work we used **WASI**

# Hyperspectral Radiometers



- Hyperspectral radiometers are used for measuring optical water and seafloor properties in in-situ conditions during the fieldwork

⇐ Hyperspectral Radiance and Irradiance Sensors for the UV, VIS or UV/VIS range (**Trios-RAMSES**)-ACC-UV: Hyperspectral UVA/UVB Irradiance Sensor: 280-500 nm

⇐ **Trios-RAMSES-ARC**: Hyperspectral UVVIS Radiance Sensor: 320-950 nm



# *In-situ* observations of the seagrass

The method of in-situ seagrass sampling has been based on the standard scheme:

## SCUBA

The seagrass is being sampled on the selected sites using transect lines, quadrant frame, single point markers, **SCUBA** gear diving equipment.

## GPS, iPAQ

The geographic coordinates of measurement path are taken by means of GPS and iPAQ, from where data are stored in GIS in laptop.

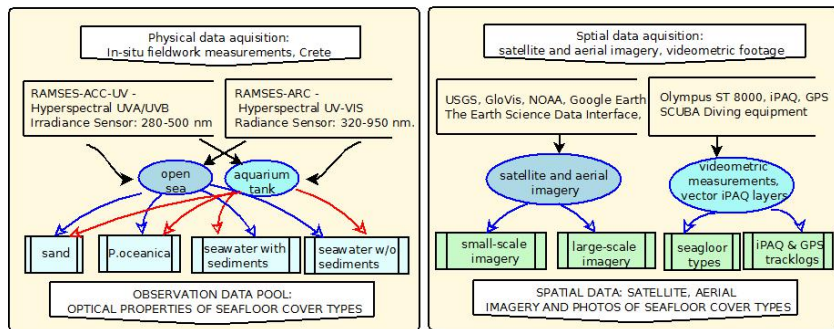
## Transect Sampling

The seagrass sampling is taken on the regular way to cover the research area

The research data include following materials:

- Google Earth aerial images and scenes from the Landsat Thematic Mapper (**Landsat TM**) and ETM+. The imagery provides information of the recent distribution of *P. oceanica* within the coastal areas
- Sampling of the in-situ measurements of the seagrass distribution. Location: northern coasts of Crete (Ligaria beach). northern Crete is suitable for the seagrass *P. oceanica* growth due to the favorable climatic (annual mean water T) and geological seafloor factors, (substrate conditions and sediments)
- Fieldwork has been carried out during the period of Sep-Oct 2010
- Results of the videographic measurements are used for the seafloor types detection, because seafloor types can be well distinguished and classified according to their optical characteristics
- Optical measurements of the irradiance and radiance of the sea water and bottom cover types of the seafloor have been received in 2009 by means of the optical sensors **Trios-RAMSES** Hyperspectral UVA/UVB Irradiance and UV-VIS Radiance Sensors by Ms. S. Noralez

## WORKFLOW FOR THE DATA ACQUISITION



# Study Area

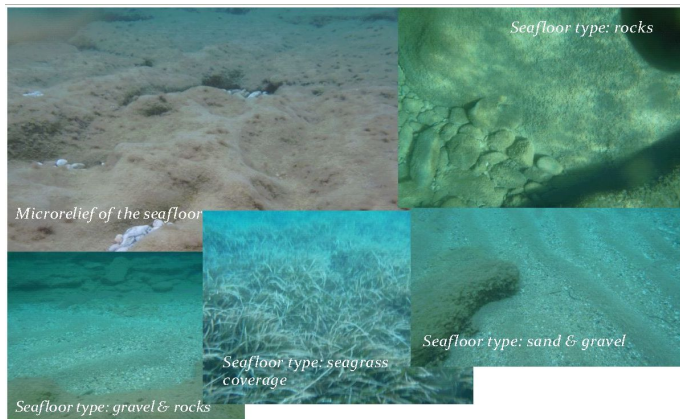
- Crete Island, Greece
- Ligaria Beach  
(36°20'N;22°59'E)
- Ligaria Beach –  
narrow, sandy  
and pebble beach



# Seafloor Cover Types: Crete Island

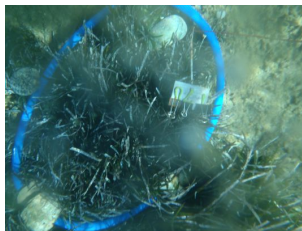
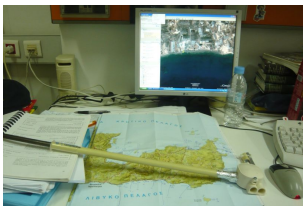


# Seafloor Cover Types: Ligaria Beach

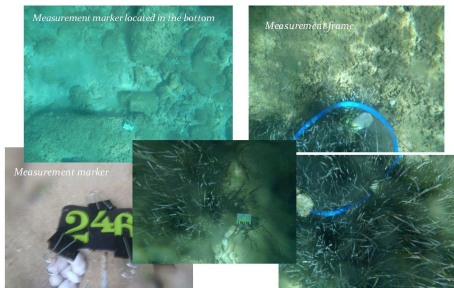


# Data Collection

Images (left to right, top to bottom): 1) Google Earth aerial imagery grabbing, Heraklion, University of Crete. 2) Sticking marker into the sea bottom in matte of *P. oceanica* for depth measurements. 3) Monitoring different seafloor cover types: matte of *P. oceanica* vs carbonate sand. 4) Placing the 0.5m circle and depth marker in the matte of *P. oceanica* for photo capture.



# Equipment (1)



Used Equipment: Three iPAQs. Three **GPS**.  
Waterproof video cameras, Olympus ST 8000.  
Markers and cords for depths measurements





## Equipment (2)



Images (from left to right, top to bottom): 1) **SCUBA** diving equipment. 2) Waterproof plastic Otterbox. 3) Boat

## Surveying

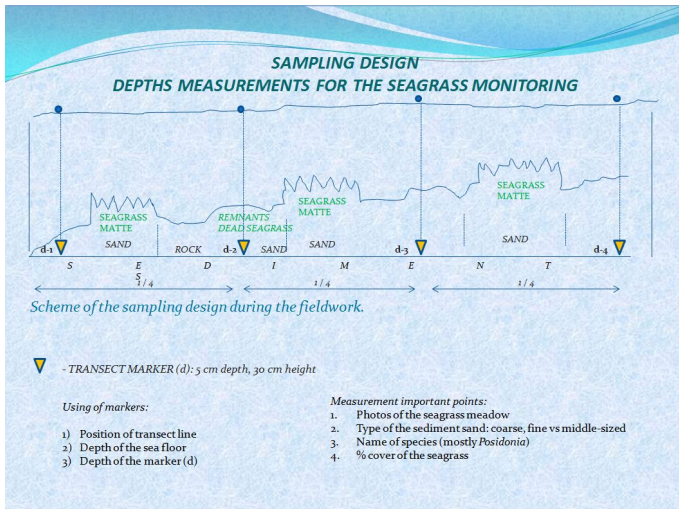
The sampling design of the fieldwork was aimed at surveying of the spatial distribution of the meadows of *P. oceanica* along northern coasts of Crete, at sampling place Ligaria beach

## Transect Sampling

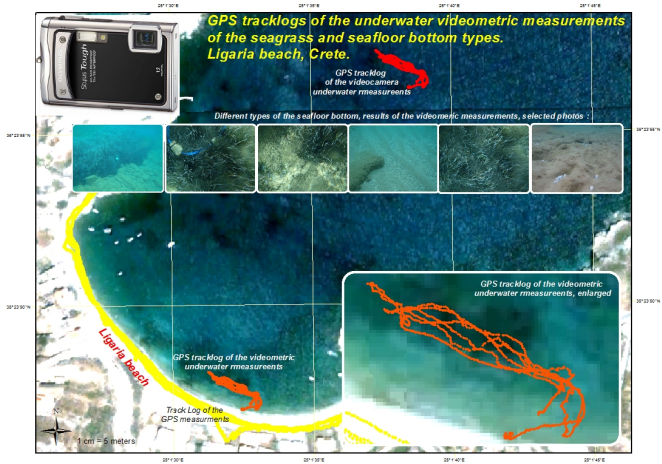
The fieldwork included several routes of the boat in the Ligaria beach sampling site, in the directions parallel to the coastline, ca 180-200 m long each one. The transect sampling method enables even and objective selection of sampling sites and covers area of growing seagrass

## Examples

Olympus ST 8010: The videometric measurements of the seafloor cover types were made using underwater video cameras Olympus ST 8010. Transect sampling method, i.e. photographs were taken along the research path. Camera were adjusted horizontally by a leveller and mounted under the bottom of the boat



# Locations of the Videometric Measurements and GPS Tracklogs



# Data Preprocessing: Raw Observations

The image shows a spreadsheet with a grid of data. A dialog box titled "Transpose" is open, showing options to "Transpose" and "Transpose and Sort". The "Transpose" checkbox is checked. The dialog also shows "Columns" and "Rows" fields, both containing "1".

Above: fragment of the spreadsheet with observed data: transposing columns to rows.

Wavelength, nm	mean	Q1	min	Q3	max	median
<b>318.23354</b>	0.030467	0.038907	0.029764	0.069762	0.116100	0.048984
<b>338.29900</b>	0.033560	0.043030	0.032847	0.076252	0.128290	0.054334
<b>358.37932</b>	0.039987	0.051320	0.039131	0.091143	0.154409	0.066354
<b>378.47247</b>	0.045786	0.058849	0.045039	0.105993	0.177150	0.078339
<b>398.57640</b>	0.052346	0.066859	0.051625	0.122328	0.201038	0.091905
<b>418.68905</b>	0.058942	0.074842	0.058240	0.138984	0.226028	0.106207
<b>438.80838</b>	0.070690	0.089761	0.069999	0.167825	0.267712	0.130580
<b>458.93235</b>	0.080107	0.102089	0.079392	0.191424	0.304933	0.149762
<b>479.05891</b>	0.086278	0.110348	0.085546	0.207940	0.332934	0.162881
<b>499.18600</b>	0.098498	0.126592	0.097689	0.239161	0.380603	0.188192
<b>519.31159</b>	0.110222	0.143976	0.109022	0.265948	0.421370	0.210237
<b>539.43363</b>	0.125694	0.166156	0.124310	0.302678	0.475842	0.240492
<b>559.55006</b>	0.131844	0.175865	0.130257	0.319385	0.503907	0.253726
<b>579.65885</b>	0.121915	0.166084	0.120186	0.302078	0.485661	0.237873
<b>599.75794</b>	0.077236	0.111113	0.075669	0.200557	0.343876	0.154016
<b>619.84529</b>	0.057038	0.085386	0.055588	0.154781	0.281737	0.117003
<b>639.91885</b>	0.050841	0.077438	0.049432	0.141810	0.265181	0.106188
<b>659.97657</b>	0.038118	0.059971	0.036997	0.110774	0.223366	0.082411
<b>680.01641</b>	0.032892	0.052265	0.032012	0.109579	0.198389	0.071686
<b>700.03633</b>	0.034756	0.058426	0.033643	0.101504	0.215413	0.075789
<b>720.03426</b>	0.026287	0.047084	0.025162	0.082940	0.193535	0.061184
<b>740.00817</b>	0.009740	0.022355	0.010145	0.042861	0.132244	0.029414
<b>759.95601</b>	0.008651	0.020234	0.009191	0.039371	0.128165	0.026558
<b>779.87573</b>	0.006019	0.014157	0.006397	0.028320	0.100314	0.019322
<b>799.76528</b>	0.008607	0.020030	0.009050	0.037323	0.118123	0.026535
<b>819.62263</b>	0.008777	0.020295	0.009288	0.037598	0.118055	0.026799
<b>839.44571</b>	0.002562	0.008010	0.002864	0.017472	0.076515	0.011432
<b>859.23249</b>	0.002653	0.006921	0.002897	0.016121	0.070377	0.009889
<b>878.98091</b>	0.002327	0.008080	0.002821	0.018625	0.082462	0.011617
<b>898.68893</b>	0.004077	0.013098	0.004709	0.031217	0.101146	0.019767
<b>918.35451</b>	0.006215	0.020162	0.007229	0.045213	0.199711	0.029950
<b>937.97550</b>	0.005783	0.026133	0.007307	0.065475	0.195073	0.040848

Preliminary statistical analysis of spectral reflectance of *P. oceanica*

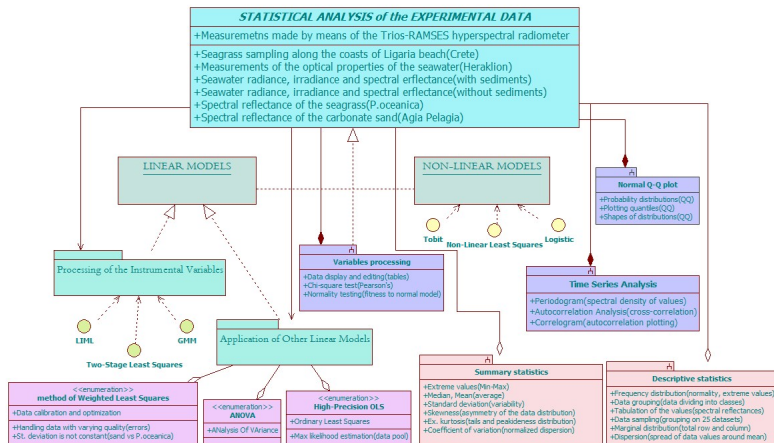
The collected data consist of the following types:

- Optical spectra of *P. oceanica*, carbonate sand, seawater with sediments and seawater measured in aquarium tank, without sediments, at different environmental conditions
- Aerial imagery from the Google Earth
- Satellite images from various open sources (**Landsat TM**)
- Results of underwater videometric measurements of the Olympus ST cameras made during the ship route

In this work we also used materials of previous measurements made by Ms. S. Noralez (dataset from 2009) using **Trios-RAMSES** hyperspectral radiometer. A data collection of visible spectra of two seafloor cover types - *P. oceanica* and carbonate sand - consist of data measured by means of **Trios-RAMSES**.

- 700 multiple measurement sets of *P. oceanica*;
- 106 for water without sediments, measured in aquarium tank;
- 27 for seawater with sediments measured in aquarium tank;
- 75 for carbonate sand;
- **Trios-RAMSES** was adjusted for automatic measurements mode, with measurements taken as fast as possible.
- **Trios-RAMSES** head was held submerged. Sampling was controlled by an operator on the surface boat.
- The head of the sensor was pointed downward at an angle of  $0^\circ$  (nadir), to capture spatial discernibility in the radiance for the benthic cover types.
- The frame was held at  $45^\circ$ , to keep sensor looking down at  $0^\circ$  (nadir view).
- A waterproof camera was attached to the platform to assist with the identification of the target object being measured

# Scheme: Statistical Approaches





## Grabbing aerial imagery from the Google Earth using Python script.



```
#!/usr/bin/env python
# -*- coding: utf-8 -*-
# Grabbing aerial imagery from Google Earth using Python script.
# This script is a simple example, it does not use any external libraries.
# It is intended for educational purposes only.

import sys
import os
import urllib2
import re
import time
import random
import string

def main():
    # Parameters
    url = "http://www.google.com/earth/data/imagery/imagery.html"
    output_dir = "output"
    num_images = 100
    image_size = 1000

    # Create output directory
    if not os.path.exists(output_dir):
        os.makedirs(output_dir)

    # Grab images
    for i in range(num_images):
        # Generate random filename
        filename = "%04d_%04d_%04d.jpg" % (i, random.randint(0, 10000), random.randint(0, 10000))

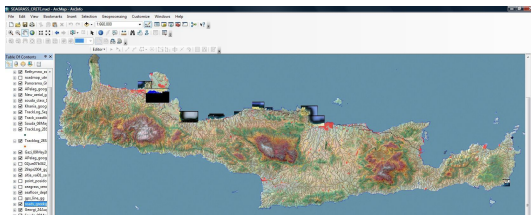
        # Download image
        url_img = url + "?imgnum=" + str(i) + "&imgsize=" + str(image_size)
        urllib2.urlretrieve(url_img, os.path.join(output_dir, filename))

        # Wait a random amount of time
        time.sleep(random.random() * 10)

    print "Done!"

if __name__ == "__main__":
    main()
```

# GIS Mapping of the Seagrass



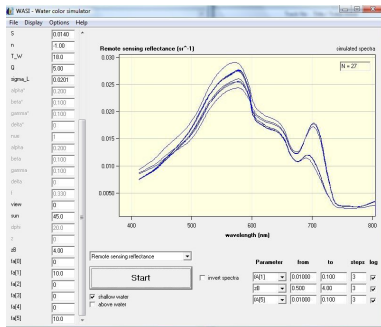
## ArcGIS

Geographic Information System (GIS): ArcGIS 10.0 was used for data exporting, conversion, organizing, integration, storage, analyses, visualizing, mapping

## Multi-Source Data Integration

Integrated approach has high potential to monitor changes in seagrass landscapes in the shallow waters of Crete. Current work integrated data from various sources: high resolution aerial Google Earth images, Landsat TM images processed by Erdas Imagine, assessment of spectral signatures by WASI, statistical analysis, ArcGIS based mapping.

- **WASI**, an **RTM** software used for artificial modelling of the seawater optical properties
- **WASI** enables simulation of radiance distribution within a water column and to understanding optical properties of the seafloor cover types
- **WASI** was chosen among other **RTM** due to the following features:
  - effectiveness
  - adaptability for the Mediterranean environment,
  - open source availability,
  - coverage of necessary wavebands,
  - clear, user friendly interface, enabling to adjust various environmental parameters.



Interface of WASI

# Spectral Simulation of the Aquatic Objects

## Spectral Simulation

The main aim of spectral simulation using **RTM** is to clarify if the bottom reflectance of two different seafloor types - mattes of seagrass *P. oceanica* and carbonate sand - differ and can be clearly discriminated during images interpretation for further mapping

## Spectral Reflectance

The remote sensing reflectance has been compared under the conditions of different water depths and cover fraction of the seafloor, in order to assess spectral signatures of the seagrass and carbonate sand as major seafloor types

## Ecological Variables

The ecological variables, specific to the field environmental conditions, were factored into the **WASI** based simulation models. Through **WASI** simulation process, imitating spectral properties of *P. oceanica* and carbonate sand for various broadband and narrowband sensors several models were created. These considered atmospheric conditions (i.e. sun zenith angle), and also height of water column, approaching the conditions to the Mediterranean Sea, and chemical content of the seawater.

# WASI Modelling Parameters: Depth and Bottom Cover Fraction

## Optical Properties

We assumed constant values of the optical properties of the seawater, phytoplankton, total amount of suspended particles and solids, atmospheric conditions, as well as Colored Dissolved Organic Matter (CDOM), which have been set up in modelling part of this work, during WASI simulations of various remote sensors.

## Simulation

The specific parameters have been chosen for the simulation of the environmental conditions of Mediterranean Sea, endemic for *P. oceanica* seagrass

## Examples

Depth Limits Although seagrass *P. oceanica* can be found until depth limits down to 40 m depth, the most preferable limits of its distribution in the Mediterranean Sea, and most suitable for the research are shallow waters until 4 meters of depth.

- Concentration of phytoplankton is accepted at the interval of  $0,035 - 0,089 \text{mg}^{-1}$
- Viewing zenith angle is near to  $90^\circ$
- Reflection factor of sky radiance = 0.0201
- Water temperature lies in the diapason  $17-25^\circ\text{C}$
- The anisotropy factor of upwelling radiation or the quality (Q-) factor is taken as 5
- Concentration of phytoplankton at the interval of  $0,035 - 0,089 \text{mg}^{-1}$
- Reference wavelength for CDOM absorption is equal to 440
- Backscattering is accepted to be  $0,00144 \text{m}^{-1}$
- Coefficient of attenuation = 1.0546
- Concentration of non-chlorophyll particles (absorption at  $\lambda 0$ ) and concentration of small suspended particles is equal to zero and ignored
- Exponent of CDOM (Gelbstoff) absorption is accepted as 0.0140
- Bidirectional Reflectance Distribution Function (BRDF) of bottom reflectance (sand) is  $0.318 \text{sr}^{-1}$

## Assumptions (3)

Parameter, WASI	Name and description	Values
C-L	Concentration of large suspended particles	8
C(i), i=0..5	Concentration of Phytoplankton	0.035-0.089 ug -1
bbS	Specific backscattering for small particles	0.005 m2g-1
T-W	Temperature of water	17-25 C
n	Exponent of Backscattering by small particles	0.005 m2g-1
Q	Anisotropy factor of upwelling radiation ("Q-factor")	5.00
sigma-L	Reflection factor of sky radiance	0.0201
bl	Backscattering coefficient of saline waters	0.00144 m-1
0	Reference Wavelength for Gelbstoff absorption	440
sun	Sun zenith angle	45.0
zB	Bottom depth	4.00
f(i), i=0...5	Areal fraction of bottom surface type number n	01/10/10
K0	Coefficient of Attenuation	1.0546
view	Viewing angle (0 = nadir)	0
C-X	Concentration of non-chlorophyllous particles (absorption at 0)	0
S	Reference wavelength for scattering of small particles	500
C-S	Concentration of small suspended particles	0
S	Exponent of Gelbstoff absorption	0.0140
C-Y	Concentration of Gelbstoff (absorption at 0)	0.400
Bn	BDRF of bottom reflectance (sand)	0.318 sr -1

- Model-specific parameters of water color simulator **WASI** adjusted to simulate environmental conditions of the Mediterranean Sea along Crete Island.
- For spectral analysis we applied forward calculations, i.e. computing and plotting of series of spectra according to specified parameter settings, with defined depths and cover fraction.

## Correlation

Finding shown the relationship between the spectral reflectance of various seafloor cover types and depth, i.e. water column height.

## Variations in spectral reflectance

Results of the in-situ fieldwork measurements revealed that spectral reflectance of *P. oceanica* varies at depths of 0.5, 2.0 and 3.5 m and differs from carbonate sand

## CZCS scanner

Studies of the broadband and narrowband sensors demonstrate that simulated spectra of the seagrass made using **WASI**, have the best results at Coastal Zone Colour Scanner (**CZCS**) scanner, especially in case of measuring ocean color.

## Examples

MODIS, SeaWiFS: Moderate Resolution Imaging Spectroradiometer (**MODIS**) and Sea-Viewing Wide Field-of-View Sensor (**SeaWiFS**) may be used for the seagrass mapping, as their technical characteristics enable to spectrally discriminate *P. oceanica* from other seafloor cover types (carbonate sand), as tested in the current work.



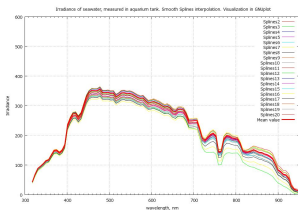
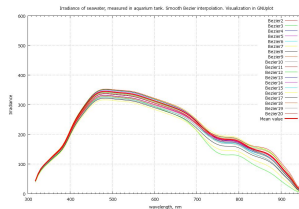
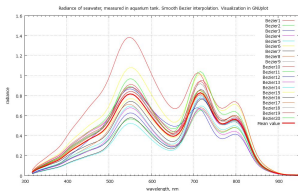
The total amount of measured data was large and included following datasets made using hyperspectral radiometer **Trios-RAMSES** in 2009:

- 350 measurement sets of *P. oceanica* reflectance for 14<sup>th</sup> Oct,
- 400 sets of *P. oceanica* reflectance for 15<sup>th</sup> Oct,
- 84 datasets for seawater reflectance with sediments,
- 105 datasets for seawater reflectance without sediments,
- 87 sets for spectral reflectance of carbonate sand

A statistical approach was used for proper processing of such amounts of data.

# Radiance and Irradiance of the Seawater **with** Sediments

## Modelling and visualization: Gretl.



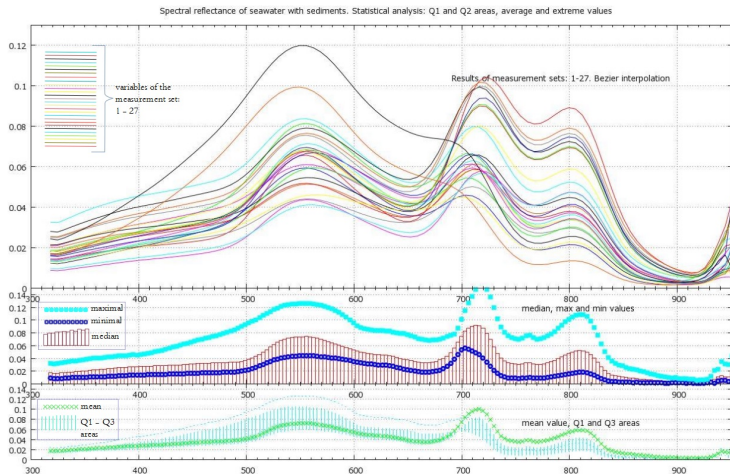
Model 6: LAD, using observations 1:01–8:23 ( $T = 1$ )  
Dependent variable: v16

	Coefficient	Std. Error	t-ratio	p
const	0.738911	0.0862011	8.5719	0
v1	-0.000775186	0.000114010	-6.7993	0

Median depend. var	0.227857	S.D. dependent var	
Sum absolute resid	30.22342	Sum squared resid	
Log-likelihood	28.74727	Akaike criterion	-
Schwarz criterion	-46.99000	Hannan-Quinn	-

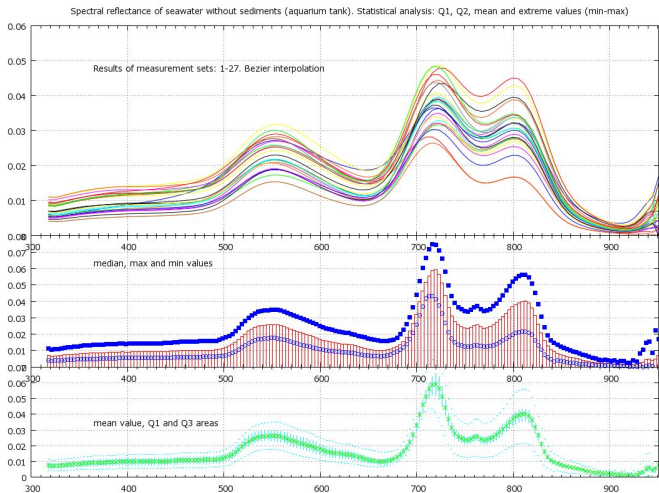
# Spectral Reflectance of the Seawater with Sediments

Measured in aquarium tank, HCMR, Crete. Visualization: Gnu Regression, Econometrics and Time-series Library (**Gretl**).



# Spectral Reflectance of the Seawater **without** Sediments

Modelling and visualization: **Gretl**.



## Optical Properties

Graphs showing optical properties of seawater with and without sediments focused on spectral variability of the water with changed physical and chemical content.

## Spectral Signatures

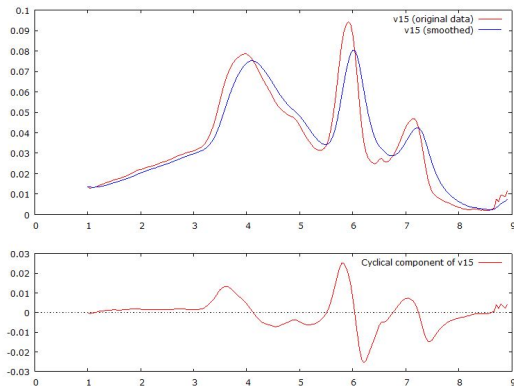
Alterations in the individual spectral signatures of single measurements reflect individual health properties of leaves: different nitrogen and chlorophyll content causing diverse color pigmentation and light absorption, water content in leaves and plant physiological conditions, which vary across seagrass meadow, shoot morphology, etc.

## Examples

Spectral Reflectance Differences in the values of spectral reflectance of the measurements taken on various days might have been caused by the impact of the atmospheric conditions, such as solar radiation and sun illumination by different zenith angle.

# Spectral Reflectance of the Seawater **with** Sediments

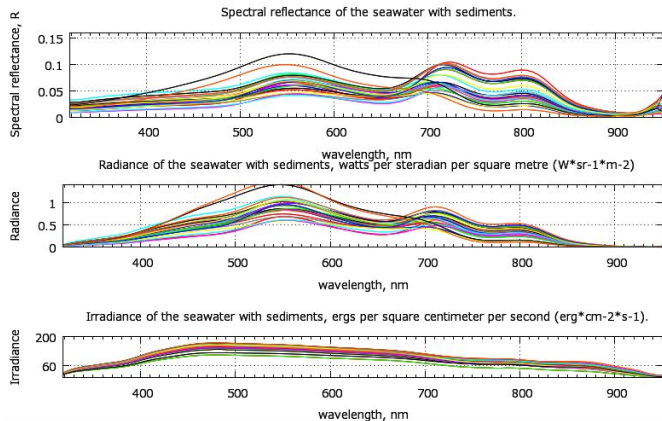
Seawater with sediments measured in aquarium. Ligaria Beach, Crete.  
Exponential moving average of spectral reflectance of seawater with sediments.  
Example below is for measured variable V15.



Modelling and visualization: **Gretl**

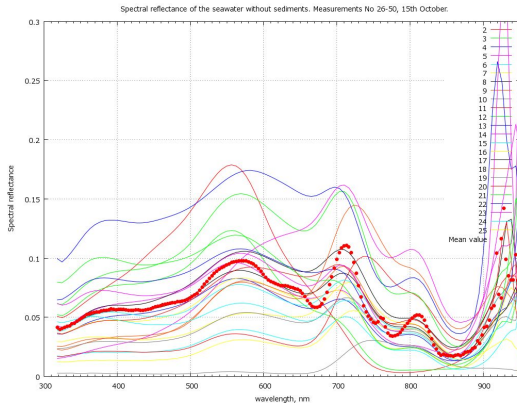
# Optical Properties of the Seawater with Sediments

Optical properties of the seawater with sediments measured in the aquarium tank, Hellenic Centre for Marine Research (HCMR), Crete



Modelling and visualization: [Gretl](#)

# Measurements of the Spectral Reflectance of *P. oceanica*



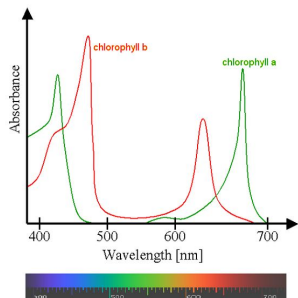
Modelling and visualization: Gretl

The reflectance spectra of *P. oceanica* show values max 450-600 nm

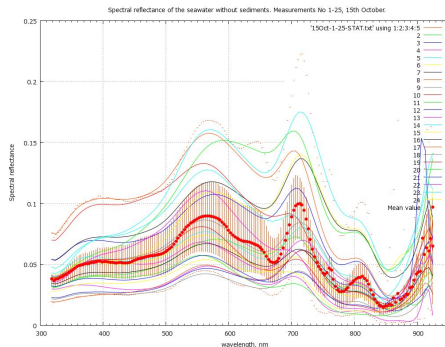
- 1 first, because of the chlorophyll absorption peak at 465 and 665nm
- 2 second, because of the weakening of CDOM (or Gelbstoff) in the blue part of the Visible Spectrum (VIS) spectrum, as it most strongly absorbs short wavelength light in blue to ultraviolet range,
- 3 finally, because the absorption of the seawater increases in the red part of the VIS spectra.



# Chlorophyll Content. Spectral Reflectance

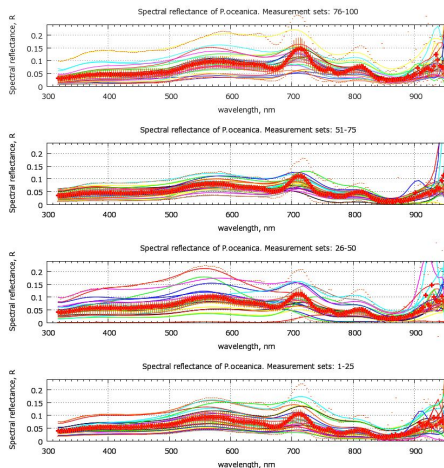


Absorbance spectra of chlorophyll in a solvent. The spectra of chlorophyll molecules are slightly modified depending on specific pigment-protein interactions. Source of picture above: Wikipedia.org.



Remote sensing reflectance of *P. oceanica*. Series 1-25. Shown midspread of the statistical quartiles Q1 and Q3 (vertical dashes) and mean value within the range. Visualization: **Gretl**.

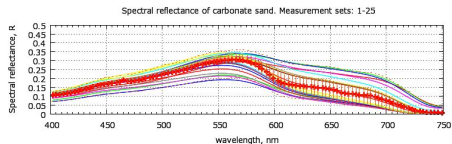
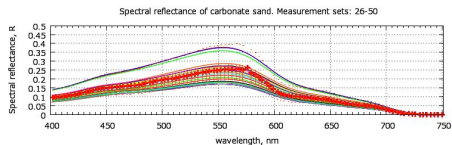
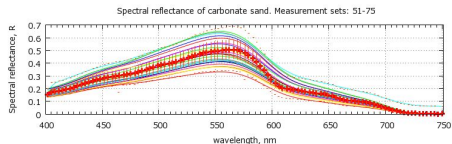
# Spectral Reflectance of *P. oceanica*



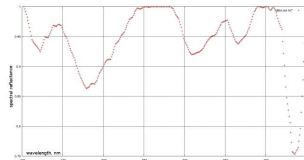
Modelling and visualization: Gretl

- The analysis of spectra shows that the appropriate wavebands for seagrass mapping lay in 500-600 nm, and has peaks at ca. 700 nm, between 680 and 710 nm.
- The highest values of the bottom reflectance are at spectra of 500-600 nm.
- The most appropriate depths at which the spectral signatures of the seagrass could be discriminated are lesser than 2.5 meters.

# Spectral Reflectance of the Carbonate Sand



The analysis of the spectral signatures of the seagrass *P. oceanica* and carbonate sand clearly shows that seagrass has spectral reflectance much lesser than that of a carbonate sand, in general not increasing values of 10% reflectance in spectra of 500-600 nm, while carbonate sand has spectral reflectance approaching 63% in its highest values than 2.5 meters.

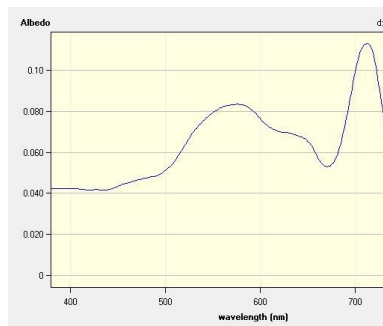
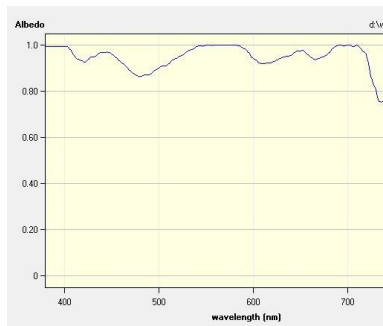


Spectral reflectance of carbonate sand. Agia Pelagia beach. Results of single measurement set made by spectroradiometer **Trios-RAMSES**

Modelling and visualization: **Gretl**

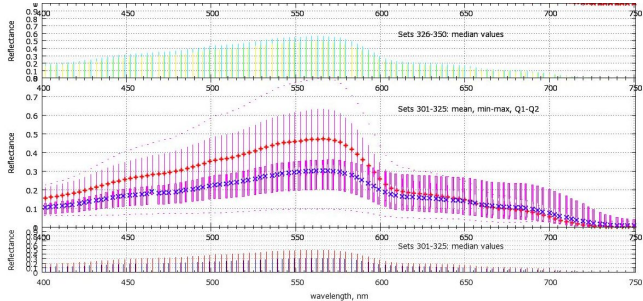
# Bottom Albedo of Carbonate Sand and Seagrass *P. oceanica*

Bottom Albedo of Carbonate Sand and Seagrass *P. oceanica*. Agia Pelagia, Crete.  
Images: Sand (left); *P. oceanica* (right). Visualization: WASI.



# Spectral Signatures: Comparison

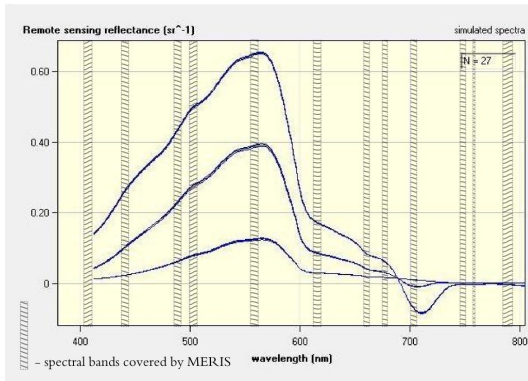
Comparative analysis of spectral signatures of *P. oceanica* and carbonate sand.



Comparison of spectral reflectance of seagrass *P. oceanica* and carbonate sand. Visualization: **Gretl**

These results indicate that seagrass *P. oceanica* can be detected and discriminated from other seafloor cover types (carbonate sand) with varying environmental conditions, i.e. water column height, by hyperspectral spectroradiometers (**Trios-RAMSES**), which positively answers the first research question of this thesis ('Is *P. oceanica* spectrally distinct from carbonate sand with varying in-situ conditions?').

# Spectral Signatures: Distinguishability

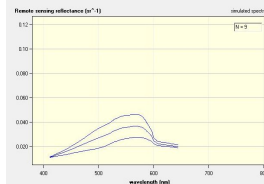
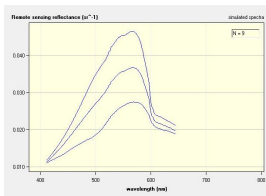
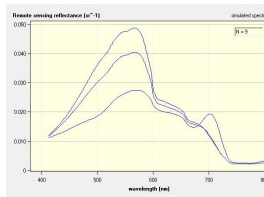
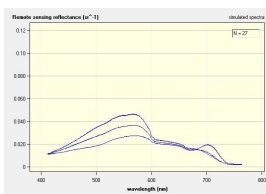


Simulated remote sensing reflectance of *P. oceanica* at various depths: 0.5, 2.0 and 3.5 m

- Distinguishability of spectral signatures of *P. oceanica* and carbonate sand.
- The results of spectral measurements at various depths shown: *P. oceanica* is spectrally distinct from other sea floor types (carbonate sand), based on differences in their spectral signatures with changing environmental conditions: increasing water column height, i.e. depths.

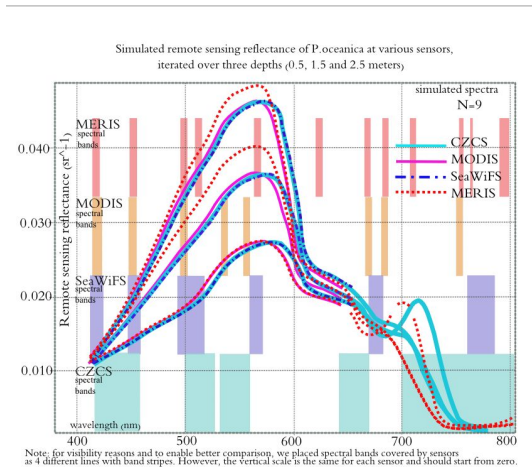
# Spectral Discrimination by Radiometric Information

Do broadband and hyperspectral sensors provide enough radiometric information for spectral discrimination of seagrass, and can be used for mapping seagrass *P. oceanica*? Separated plots of simulated RS reflectance of *P. oceanica* at various sensors: MODIS, Medium-Spectral Resolution, Imaging Spectrometer (MERIS), SeaWiFS and CZCS, iterated over three depths



# Comparison of Various Sensors

Combined plots of simulated remote sensing reflectance of seagrass *P. oceanica* at various sensors: MODIS, MERIS, SeaWiFS and CZCS, iterated over three depths, as stripes shown spectral bands covered by these sensors





## WASI

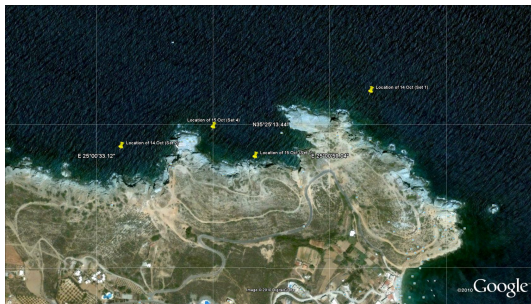
Studies of simulated spectra of the seagrass, made using WASI modeller, demonstrated best results at CZCS multi-channel scanning radiometer, especially devoted to the measurement of ocean color. The spectrum of *P. oceanica* reflectance, simulated for CZCS, covers the wavelength interval of 400-800 nm, and is distinctive for various depths.

## CZCS

The second research question of this MSc thesis ('Do broadband and hyperspectral sensors provide enough radiometric information for spectral discrimination of seagrass, and therefore, can be used for mapping of *P. oceanica* ?') is therefore answered with 'yes', and the most suitable sensor is the CZCS.

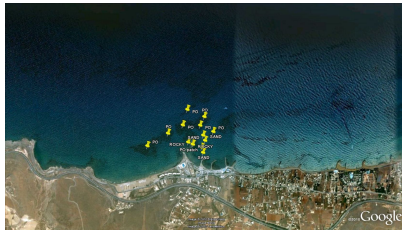
# Google Earth: Seagrass Meadows

The in-situ field large-scale metre-level level of seafloor monitoring was then upscaled to airborne Google Earth aerial imagery interpretation, to provide a meadow-level view of seagrass landscapes. Enables to analyze environmental changes within seagrass landscapes based on data from various sources: aerial and satellite images, geographically referenced maps of Crete island and results of images classification showing areas of seagrass distribution.

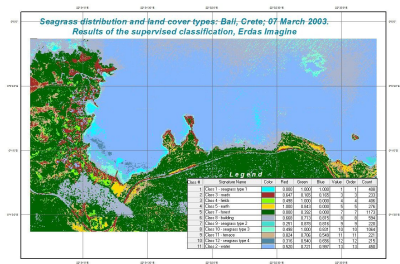
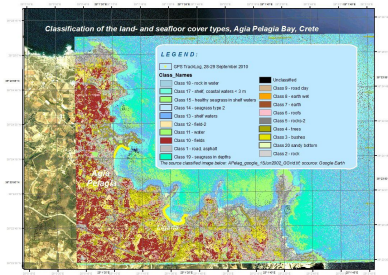


# Google Earth Imagery: Seafloor Classification

Supervised classification is based on training sites of seafloor cover types. Spectral properties were used for classification of the seafloor types: carbonate sand, patches and meadows of *P. oceanica* and rocks. The classification is based on the properties of the seafloor cover types, including *P. oceanica*: brightness, color, texture and structure of the seagrass mattes.



The analysis of the imagery of the Cretan coasts is based on the images classification and is aimed to investigate the distribution of the seagrass *P. oceanica* within the research area.  
Figures: Unsupervised classification (left). Supervised classification (right).



# Unsupervised Classification

Correctly classified	Rocky bottom	Shelf, < 3m	Healthy seagrass	Seagrass <i>Pocernica</i>	Carbonate sand	Shelf waters, 0-3m	Shelf waters, 3-7m	Deep waters, > 7m	Fields: corn, greens	Roads: asphalt+ground	Seagrass, other > 3m	Ground	Buildings (roofs)	Trees	Bushes	Total	$\kappa$ producer accuracy
Rocky bottom	14	2	0	0	3	0	0	0	0	1	0	2	0	1	1	24	0.58
Shelf, < 3m	0	12	0	3	1	2	0	0	1	0	0	0	1	0	0	20	0.60
Healthy seagrass	0	1	10	3	2	0	0	0	1	0	2	0	0	0	0	19	0.52
Seagrass <i>Pocernica</i>	0	1	1	13	0	1	0	0	1	0	2	0	0	1	1	21	0.62
Carbonate sand	2	0	0	0	16	0	0	0	0	0	0	2	0	0	0	20	0.80
Shelf waters, 0-3m	0	3	0	0	0	9	2	0	0	0	0	0	0	0	0	14	0.64
Shelf waters, 3-7m	1	2	0	0	0	3	8	1	0	0	0	0	0	0	0	15	0.53
Deep waters, > 7m	1	1	0	0	1	2	3	16	0	0	1	0	0	0	0	25	0.64
Fields: corn, greens	0	0	0	0	0	0	0	0	14	0	0	0	0	3	4	21	0.66
Roads: asphalt+ground	1	0	0	0	1	0	0	0	0	5	2	0	0	0	0	9	0.55
Seagrass, other > 3m	0	0	0	3	0	0	0	0	0	0	24	2	0	1	1	31	0.77
Ground	1	0	0	0	0	0	0	0	0	0	0	11	3	1	1	17	0.65
Buildings (roofs)	0	0	0	0	2	0	0	0	0	0	0	0	9	2	3	16	0.56
Trees	0	0	2	0	0	0	0	0	0	0	0	0	0	7	3	12	0.58
Bushes	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	6	0.66
Total	20	22	13	22	26	17	13	17	17	6	31	17	13	18	18	270	-
$\kappa$ user's accuracy	0.70	0.55	0.77	0.59	0.62	0.53	0.62	0.94	0.82	0.83	0.77	0.65	0.69	0.39	0.22	-	0.64

## Kappa Accuracy

Overall Kappa ( $\kappa$ ) accuracy is calculated using the formula:  $\sum A = N$ , where A is number of correctly mapped points (172) and N is the total number of points (270). Thus, according to the results the overall accuracy =  $172/270 = 0.6370$ , which is 64%. Overall accuracy for unsupervised classification = 64%.

## User's Accuracy

Users' accuracy (Reliability of classes) varies between 0.22 and 0.94 depending on class, which proves that supervised classification has better results for seagrass mapping than the unsupervised classification. Producer accuracy lies in interval between 0.52-0.77, according to class.

# Supervised Classification

Correctly classified	Seagrass-1	Roads	Fields	Earth	Forest	Buildings	Seagrass-2	Seagrass-3	Terrace	Seagrass-4	Water	Total	$\kappa$ producer accuracy
Seagrass Psecomitris	22	0	0	0	0	0	2	1	0	1	1	27	0.81
Roads	0	18	0	3	1	2	0	0	0	0	0	24	0.75
Fields	0	1	10	0	3	0	0	0	1	0	0	15	0.66
Earth	0	1	1	13	0	1	0	0	1	0	0	17	0.76
Forest	0	1	1	1	9	0	0	0	1	0	0	13	0.69
Buildings	0	0	2	0	1	24	0	0	1	0	0	28	0.85
Seagrass-2	3	0	0	0	0	0	33	2	0	2	2	42	0.78
Seagrass-3	1	0	0	0	0	0	1	27	0	1	1	31	0.87
Terrace	0	2	3	1	0	1	0	0	19	0	0	26	0.73
Seagrass-4	1	0	0	0	0	0	2	2	0	37	1	43	0.86
Water	2	0	0	0	0	0	1	1	0	1	14	19	0.74
Total	29	23	17	18	14	28	39	33	23	42	19	285	-
$\kappa$ user's accuracy	0.76	0.78	0.59	0.72	0.64	0.86	0.85	0.82	0.83	0.88	0.74	-	0.72

## Kappa Accuracy

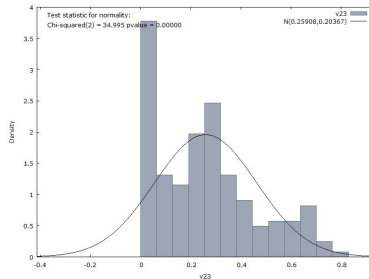
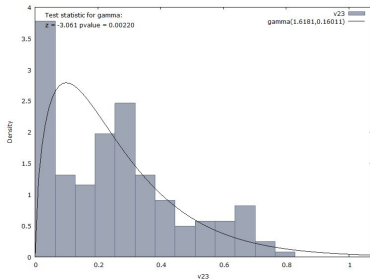
Overall Kappa ( $\kappa$ ) accuracy is calculated using the formula:  $\sum A = N$ , where A is number of correctly mapped points (226) and N is the total number of points (285). Overall  $\kappa$  accuracy for supervised classification = 72%.

## User's Accuracy

Users accuracy (Reliability of classes) varies between 0.59 and 0.88 depending on class. Producer accuracy lies in interval between the 0.66- 0.87 according to class.

# Normality Testing

Frequency normality test against **gamma distribution** (image left) and **normal distribution** (image right): radiance of the seawater, measured in the aquarium tank.



## Approach

An approach of the seagrass spectral analysis, monitoring and mapping was undertaken in this work. It integrates various research techniques and tools, combining **RS** methods of spectral analysis of the seafloor cover types and information on the ecology of *P. oceanica*. The research contributed towards development of methods of the seagrass spectral optical discrimination for the seagrass mapping based on the aerial imagery classification.

## Correlation

Correlation between the optical properties (spectral reflectance) of the seafloor cover types and hydrological parameters of the environment has been studied. The limitations and capabilities of the broadband and narrowband sensors under the conditions of altering environmental parameters were analyzed.

## Recommendations

For further development of the **RS** based monitoring and mapping of seagrass and seafloor types it is recommended to perform upscale mapping applying bathymetric data.

## Explanations

Landscape fragmentation and patchiness in the seagrass meadows are caused by natural reasons and human effects (e.g. ocean trawling).



## Remote Sensing

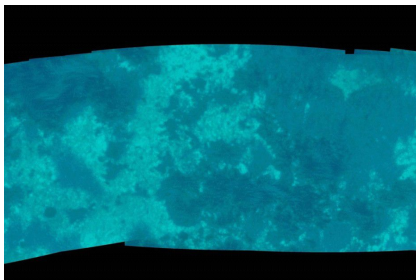
**RS** application towards seagrass mapping is based on the assumption that various types of the seafloor bottom have different reflectivity characteristics which is visually expressed in distinct objects colors (*P. oceanica*, carbonate sand).

## Sediments Reflectivity

In turn, reflectivity of sediments is affected by water optical properties and content (suspended particles, microalgae, etc).

## Optical Properties

Measuring optical properties of the seawater allows to calculate spectra of the objects and to discriminate them on the aerial and satellite images which enables spectral discrimination of submerged vegetation and other seafloor cover types



Images: Seagrass meadows (left) and Seagrass mattes (right).

Hierarchical principles of the seagrass landscapes are based on the quantitative analysis of the spatial patterns, consisted by the components and separate elements:

- **Patches**: bunches of individual shoots construct of seagrass, arranged into discrete clumps of mattes (scale: several cm-meters).
- **Mattes** create beds with 1-100m in diameter.
- **Beds** are arranged into homogeneous, continuous seagrass meadows that may reach in size from tens to 100s m and extend to several km areas.
- **Meadows** are sometimes defined as landscapes.

## Goal

The goal of this MSc research was to explore the perspectives, advantages and limitations of the narrowband and broadband sensors for the environmental mapping and monitoring of *P. oceanica* seagrass along the coasts of Crete Island.

## Methodology

The methodology of the spectral discrimination of seafloor cover types designed in the frame of this research includes:

- Application of the remote sensing **RTM** techniques
- Data from broadband sensors, hyperspectral radiometers for measurements of the seawater optical properties
- Categorical and continuous statistical analysis for data processing
- **GIS** software for image visualization, classification and analysis

The results of this work demonstrated following issues:

- Application of the RS data from the broadband sensors is highly advantageous for the seagrass mapping
- Spectral discrimination of *P. oceanica* from other seafloor cover types is possible at diverse and changing environmental conditions (water column height)
- *P. oceanica* is spectrally distinct from other seafloor types (carbonate sand) at varying environmental conditions, as well as from other seagrass species (*Thalassia testudinum*)
- The **RTM** software is a useful tool for analyzing spectral signatures of various seafloor types enabling simulations of data received from the broadband and narrowband remote sensors.

- extend study area over the whole Crete Island
- extend temporal period of the imagery coverage (subject of data availability)
- apply various classifications methods for the imagery to compare results accuracy and precision
- consider various factors determining the effect of the ecology, health and spatial distribution of *P. oceanica* (besides bathymetry and chemical content of the seawater)
- in upscaling to the small-scale mapping level, further environmental variables need to be considered: health conditions of the seagrass, hydrology, geomorphology
- other **RTM** software may be tested and modelling outcomes compared
- application of various open source **GIS**

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*Thank you for attention !*

Acknowledgement:  
The presented research has been funded by the  
*Erasmus Mundus Scholarship*  
Grant No. GEM-L0022/2009/EW,  
for author's MSc studies (09/2009 - 03/2011).

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