European Water 58: 185-190, 2017.

Earth Observation based monitoring in Natura-2000 sites, providing ecosystem services for their adaptive management

A. Zouboulis[1*], A. Tsirika[2], E. Terzopoulou[3], G. Skoufas[4], I.-D. Adamakis[3], S. Kyriakidis[3], V. Liakopoulos[3], N. Tziolas[2] and G. Zalidis[2]
[1] *Aristotle University of Thessaloniki, Department of Chemistry, Laboratory of Chemical & Environmental Technology, 54124 Thessaloniki, Greece*
[2] *Aristotle University of Thessaloniki, School of Agriculture, Laboratory of Remote Sensing, Spectroscopy and GIS, 54124 Thessaloniki, Greece*
[3] *Interbalkan Environment Center, Loutron 18, 57200, Lagadas, Greece*
[4] *Alexander Technological Educational Institute of Thessaloniki, Department of Civil Engineering, 57400, Sindos, Greece*
[*] *e-mail: zoubouli@chem.auth.gr*

Abstract: Epanomi and Aggelochori lagoons and their wider coastal-marine zone are situated in the eastern part of Thermaikos Gulf (N. Greece, near to Thessaloniki) and are considered as very important natural sites, because they include priority marine habitat types, according to 92/43/EEC Directive, i.e. 1120* (*Posidonia beds*) and 1150* (*Coastal lagoons*). The implementation of Water Framework Directive requires both lagoons to achieve good ecological Status in these coastal water bodies and to conserve their habitats. The objectives of this work were to develop an innovative monitoring system in order to provide ecosystem services, in almost real time, for the adaptive management and enhancement of conservation status of coastal habitats. The monitoring of water quality included the assessment of biotic and abiotic factors and it was implemented via the combination of destructive (active and passive sampling based on an early warning system, followed by laboratory analysis) and non-destructive methods (earth *in situ* monitoring, using an Autonomous Water Telemetry Sensing System (AWTSS), employing spectra sensors and space-born remote sensing data). The main objectives of monitoring, in addition to develop an efficient operational monitoring protocol, based on integrated Earth Observation (Earth *in situ* and space-borne) data, include the evaluation of management effectiveness and the establishment of a feedback mechanism, used to provide ecosystem services for the effective adaptive management. In addition, the performed monitoring was able to provide the ecosystem services needed for the adaptive management, proposed for these habitat types, and to serve the relevant stakeholders.

Key words: coastal water bodies-habitats; ecosystem services through Earth observation; innovative integrated monitoring system

1. INTRODUCTION

The increased urbanisation and industrialisation in several Mediterranean coastal areas, especially during the last decades, has generally led to the degradation of water quality and of marine habitat types (Claudet and Fraschetti, 2010). The main issues include water and sediment eutrophication, pollution, disruption of the sedimentation/erosion balance along the coast, direct destruction imposed by human modifications of the coastline, degradation by boat trawling and anchoring, etc. (UNEP/MAP, 2005; EEA, 2006; Airoldi and Beck, 2007). Epanomi lagoon (including its wider coastal-marine zone) and Aggelochori lagoon (including a saltpan, salt marshes and the marine zone) constitute areas of NATURA 2000 network with SCI codes GR1220012 and GR1220005, respectively. Both sites are characterized by high ecological importance and they host priority marine habitat types and species. Specific actions for the conservation of coastal habitats and significant avifauna species in those two NATURA 2000 network sites were implemented under the frame of ACCOLAGOONS project (LIFE+ NATURE AND BIODIVERSITY).

The sustainable water resource management supports multiple water-dependant economic activities, and conserves aquatic resources, while protecting public health. However, the required environmental health decisions need to be supported by real-time sophisticated water monitoring systems, noting that monitoring constitutes an essential tool towards the conservation of species, habitats, ecological and developmental processes it is strongly related to the sustainable management (Borja et al., 2009). Monitoring is crucial for the assessment of conservation status, regarding the structural and operational characteristics of a natural system, for the evaluation of efficiency, regarding the management measures implemented in the affected area, for the early diagnosis and prediction of degradation problems, etc. Regarding water quality, the application of traditional methods for monitoring biotic and abiotic factors have been performed during the past decades mainly by the *in situ* measurements and/or data collection, as well as sampling and transfer to appropriate chemical or biological laboratories for further analysis and evaluation of collected samples. However, the recent advances in communication and sensor technologies have accelerated the progress of remote monitoring capabilities, applied for water quality (Bonin–Font et al., 2016). In several cases the recent monitoring programs have been directed towards the inclusion of continuous data collection, by using appropriate *in situ* detectors. These data may be accessed either through on-site downloading, or even remotely. The application of Autonomous Surface Vehicles (ASVs) is rapidly becoming popular and rather common place within the marine and aquatic science community (Caccia, 2006; Dunbabin et al., 2009).

The main aim of this research is the contribution to environmental protection and sustainable use of marine resources, through the planning and development of tools, for implementing actions in the framework of Integrated Coastal Zone Management (ICZM). The current study presents a novel robotic exploration system, equipped with a set of advanced technological capabilities. The system enables a range of application cases in a variety of operational environments and in almost real-time, providing added-value services for knowledge-based applications, such as adaptive management and enhancement of conservation status, regarding coastal habitats, as well as tracking the enhancement of conservation status of common marine habitat types, resulting from the implementation of management actions under the frame of «LIFE + Nature and Biodiversity 2009» ACCOLAGOONS project.

2. MATERIALS AND METHODS

The development of the respective Monitoring Program included the determination of parameters to be measured, the methodology and the frequency of monitoring, as well as the location of appropriate sampling points. In order to estimate the success of implemented management measures, the monitoring protocol of “ACCOLAGOONS LIFE + Nature & Biodiversity” project was considered. The monitoring of water quality included the assessment of biotic and abiotic factors and it was implemented through the combination of destructive and non-destructive methods. Sampling, preservation and analytical protocols are conducted according to the respective Standard Methods for the Examination of Water and Wastewater (22nd Ed.). The samples were collected every month from nine sampling sites (Figure 1a.).

The importance of non-destructive monitoring is well known, as it can tackle several limitations that can occur with the application of destructive *in-situ* methods, most importantly the high cost and the low spatial and temporal resolution of such campaigns. In this context, the ATWSS was utilized, enabling the “clever” capturing of a wealth of information from the water systems and hence, facilitating the smart water management.

The biotic factors, which were monitored, were the coastal and marine benthic biocommunities, emphasizing in *Posidonia oceanica* meadows, and the phytoplankton communities. The main abiotic factors which were monitored *in situ* were: pH, temperature, salinity, specific conductivity, Dissolved Oxygen and turbidity. Furthermore, specific samples were collected in order to perform supplementary water analysis at the Laboratory (*in vitro* measurements). The main parameters which were measured in this case were nutrients (nitrate, phosphate, nitrite, silicate and ammonium ions), heavy metals (cadmium, lead, arsenic, nickel, iron and chromium), pesticides (over 100 pesticides), organic content (TOC) and biological indicators (chlorophyll a).

2.1 Technical description of the autonomous water telemetry sensing system

ATWSS prototype consists of mechanical and electrical hardware components and a remote sensing platform, as illustrated in Figure 1b. ATWSS has designed in order to be easily maneuvered in various water bodies and can carry different types of sensors and processing data systems. In the lower part of this system all the electronic equipment, the sensors, the motor and the hardware automation are situated, while in the upper part two Wi-Fi antennas, four solar panels, an anemometer and a IP camera were placed. The two parts are firmly sealed to each other, offering full isolation to water securing all-weather functionality. At the front of the vessel an electric Minn Kota motor can keep the vessel “anchored” within 3 meters of a specific control or sampling point. The motor can store up to 6 pre-defined paths, a feature that is very useful for systematic and targeted water monitoring missions.

The ATWSS was developed using a “plug and play” architecture, hence all sensors, power supplies and communications can be adjusted (even by a non-expert user) to the current needs. The vessel is powered by 2 rechargeable batteries, which can be charged during the mission via the 4 solar panels, located on the top part of the vessel. As a result, the AWTSS can operate continuously for at least 4 h, enabling the mapping of large areas within the time framework of a single mission.

Additionally, it is equipped with an electrical winch, with a 30 m stainless wire rope, which can be used in conjunction with a multi-parameter probe, or with an active sampler for water profiling applications. Furthermore, the prototype can carry a variety of passive samplers for water quality monitoring, as well as depth sonar in order to perform bathymetric sounding surveys.

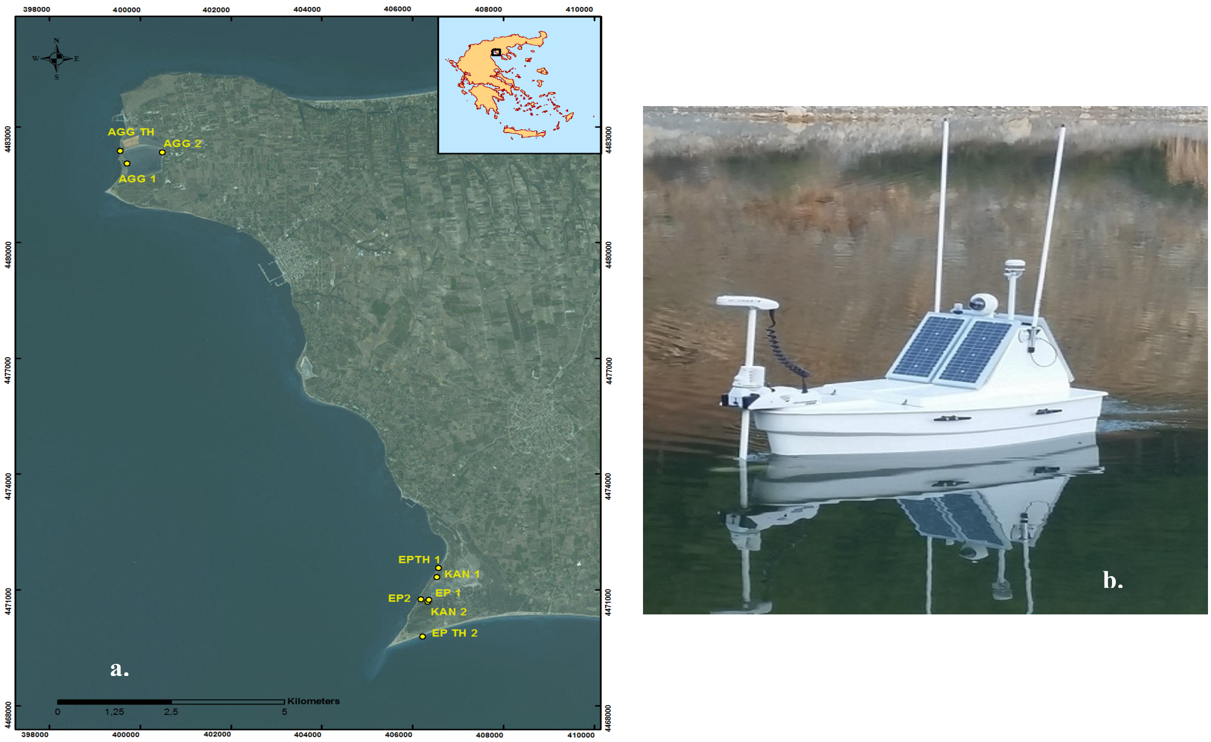

Figure 1. a. Epanomi and Aggelochori sites and the sampling points, b. Autonomous Telemetry Water Sensing System (ATWSS).

The collection of measurements requires an accurate and robust protocol at the highest level of standards to facilitate the subsequent data processing step. Considering this, the main rationale is to offer certified *in-situ* observation data through the application of telemetry, adhering to the same principles and standards, as the working Group on Earth Observation System of Systems and Open Geospatial Consortium, standard information models related to Water (WaterML). Therefore, the AWTSS is continuously connected to a base station (platform) for data transferring and handling. The operator has full control of the vessel navigation and of the sampling procedure. For this reason, custom software with a Graphical User Interface was specifically developed. In addition, the operator has optical contact with the environment around, as well as inside the platform, by using the two IP cameras that are installed; one located externally at the top part, and one located internally at the bottom part.

In order to connect with the base station (platform), the AWTSS can employ 3 different telecommunication modes: (1) Local Wireless LAN connection, (2) Remote operation by using the cellular network (telemetry), and (3) RC operation by using a remote control programmed with the basic functions of the vessel, such as speed, direction and spot-lock, with effective range up to 20 km. In addition to these communication modes, the vessel can be activated and deactivated remotely and notify the operator in case of low battery level, or even theft protection, via SMS.

3. RESULTS AND DISCUSSION

Under the frame of the current survey, the following marine habitat types (included in the Annex I of the Directive 92/43/EC, or not) were identified in both sites: 1110 – Sandbanks, which are slightly covered by sea water all the time, *1120 - *Posidonia beds (*Posidonion oceanicae*), *1150 - *Lagoons, 1170–Reefs, 119A-Soft substrata without vegetation, and 119B-Soft substrata with vegetation.

The range of selected measured parameters (from *in situ*, as well as from laboratory data, including the measurements taken by AWTSS) in the nine sampling sites of the two examined lagoon cases during April-November 2016 are presented in Table 1. Furthermore, the concentrations of selected heavy metals (cadmium and lead) are presented in Figures 2a & b. The observed toxic phytoplankton taxa are shown in Figure 3.

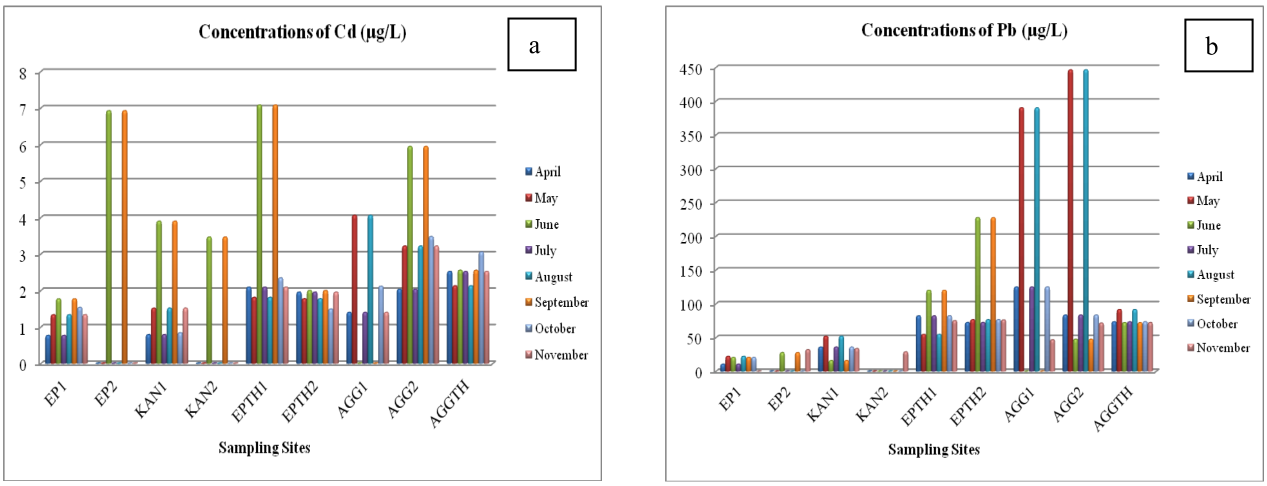

Figure 2. (a) Concentrations of Cd and, (b) concentrations of Pb, during the period April-November 2016.

An evaluation of ATWSS operation has been performed under real conditions at 25th of Nov. 2016. For the performance evaluation several laboratory measurements were also obtained and compared, highlighting a significant agreement with the relevant values, obtained from AWTSS. The testing and validation of measurements' protocol has been carried out, resulting approximately up to 80 measurements/h. Moreover, the findings and testing activities will allow the refinement of prototype sub-systems to meet the targeted application needs. Another development strand concerns the ATWSS ability to support aerial data calibration. Besides the vicarious calibration of the air-spaceborne sensors, these data can be also used for the development of prescription maps.

Generally the environmental situation differs, depending on the monitored water bodies, as well as on the period/season of monitoring (winter-spring-summer-autumn). E.g. during the summer period the water level decreases, as expected, which leads to an increase of pollutants' concentration. On the other hand, during the winter period high rainfall incidents are usually observed and as a result, the whole region of Epanomi wetland is covered with water, increasing significantly also the volume of water in *Epanomi lagoon*. This situation leads to a reduction of all pollutants' concentrations, due to dilution effect; noting also that the organic content is high, especially in Epanomi lagoon. This is a common fact in most lagoons, as well in wetlands, due to the presence of generally shallow waters. pH, temperature, salinity, specific conductivity, Dissolved Oxygen, total dissolved and suspended solids and turbidity values are considered to be at normal (expected) levels. The concentration of nutrients is highly depending to the respective monitoring period and to the non-treated effluents that are disposed in the monitoring areas, indicated as point- or diffuse pollution, whose origin however, cannot be easily determined.

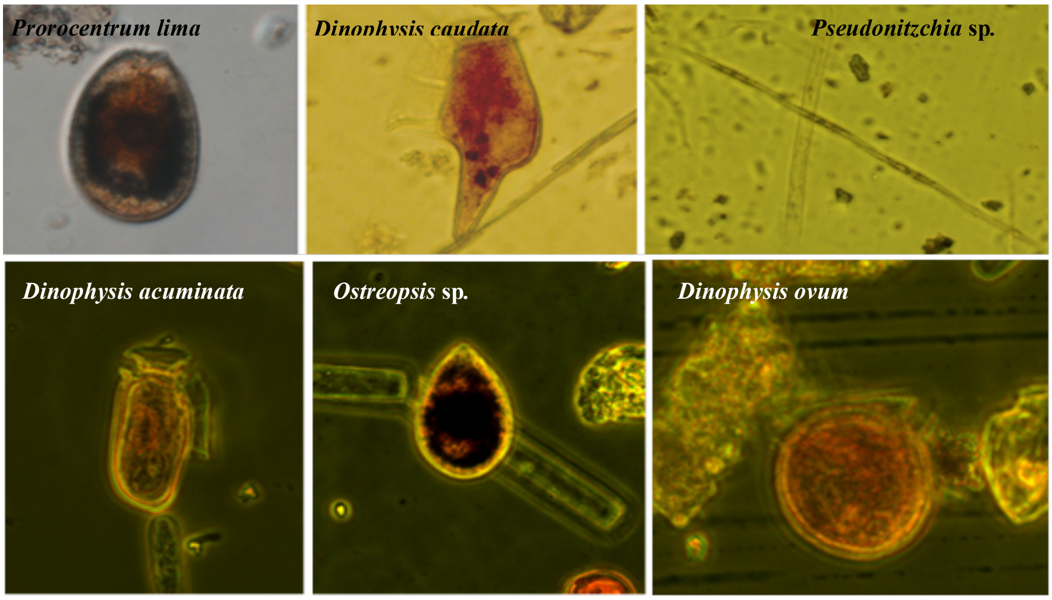

Figure 3. Photos (received by optical microscope) of potentially toxic phytoplankton species.

Table 1. Range of selected measured parameters.

Parameters		EP1	EP2	KAN1	KAN2	EPTH1	EPTH2	AGG1	AGG2	AGGTH
Temperature	°C	.	8.7-31.7	10.3-32	9.3-29.3	10.8-28.5	13.5-27.3	8.2-35.6	8.5-35	13.1-30.3
pH		7.9-8.68	6.5-9.3	5.67-9.5	7.1-8.75	7.7-9.01	6.69-8.24	6.46-8.78	6.62-8.14	6.82-9.5
EC	mS/cm	21.19-68.49	35.5-941.7	26.07-855.2	20.3-548.8	40.6-172.7	41.4-170.6	38.59-739.9	34.12-726.7	35.63-165.3
Salinity	ppt	12.72-45.39	22.4-60	21.29-68.9	13.63-68.19	30.4-64.67	41-68.53	24.7-58.2	20.88-48.4	28.8-67.84
TDS	g/L	13.79-44.7	23.1-153.3	23-298.9	14.69-409	20.45-112.4	21.14-111.3	25.18-941.6	22.01-979.3	28.29-107.4
Turbidity	NTU	117-2170	103-622	25.7-1950	85.5-590	17-292	28-136.8	47.5-2200	25.3-2500	35.5-157.6
DO	mg/L	8.3-12.1	2-11.4	0.98-10.4	0.123-10.5	5.6-10.73	5.7-10.1	2.92-11.4	3.92-11.1	6.72-10.56
TN	mg/L	0.73-1.11	n.d.	0.446-0.45	n.d.	n.d.-0.02	0.02-0.1	n.d.	n.d.	n.d.
TOC	mg/L	56.82-85.23	n.d.-51.3	19.45-22.6	n.d.-23.1	2.05-2.36	2.51-4.57	12.15-17.36	14.26-21.2	2.04-2.68
TSS	mg/L	122.4-2386	64-204.4	41-668	60-113.6	35.52-90.8	38.4-92.4	56.64-202.4	64.9-316	33.9-110.4
Total Phosphorous	mg/L	0.02-5.33	0.01-0.07	0.01-0.91	0.01-0.91	0.01-0.05	0.01-0.03	0.03-0.06	0.02-0.26	0.01-0.18
PO_4^{-3}	mg/L	n.d.-16.34	n.d.-0.22	0.18-2.79	0.12-2.79	0.03-0.15	0.09-0.49	0.09-0.18	0.06-0.8	0.12-0.55
NO_3^-	mg/L	7.53-25.87	0.5-12.4	0.8-14.17	0.6-14.17	0.3-10.63	0.4-16.39	0.6-12.84	0.4-21.7	0.4-14.2
NO_2^-	mg/L	n.d.-0.07	n.d.-0.07	0.03-0.16	0.01-0.07	0.03-0.06	0.03-0.07	n.d.-0.07	0.03-0.1	0.03-0.07
NH_4^+	mg/L	n.d.-0.78	0.08-0.6	0.03-0.36	0.08-0.89	0.04-0.53	0.05-0.53	0.09-0.66	0.08-0.54	0.04-1.21
SiO_2	mg/L	1.18-17.69	0.73-11.25	1-6.27	1.63-17.05	0.49-1.35	0.38-7.42	0.45-7.66	0.36-8.3	0.36-2.87

The same situation is prevailing in the Aggelochori area. During the summer period the water level decreases, which leads to an increase of pollutants' concentration, mainly at the two sampling points of *Aggelochori lagoon*. pH, temperature, salinity, specific conductivity, Dissolved Oxygen, total dissolved and suspended solids and turbidity values are considered to be at normal levels, despite the fluctuation in the concentration of nutrients, which are mostly depending on the respective monitoring period, as well as to the non-treated effluents that are being disposed in the monitoring area, most of measured parameters remain at normal levels.

In terms of biological species composition, phytoplankton in lagoons is poorer, than the neritic phytoplankton. It is frequently enriched by benthic diatoms, which, due to the small depth of lagoons, can be suspended by the wind. In addition, neritic species enter passively from the sea and remain in the lagoon for a period of time. In particular, the diatoms are rather few, restricted mostly to the marine channels, while dinoflagellates (*Oxyrrhis marina, Goiniodoma sphaericum, Peridinium depressum* and *Gymnodinium heterostriatum*) are quite well represented, especially in the innermost part of the lagoon. Moreover, the potential toxic species of *Dinophysis* sp. and *Ostreopsis* sp.*, Pseudonitzchia* sp. and *Prorocentrum lima* were also observed (Figure 3).

The increase of human activities in the coastal area of Epanomi and Aggelochori directly reflected on water quality and indirectly to the conservation of habitats and species. The existence of pollutants in the project area comes mainly from the diffused untreated effluents of the surrounding area's seasonal cultivation and from the point throwing wastes.

Due to the relatively short time of monitoring period after the completion of recently applied restoration works for the improvement of lagoons' environment, the overall assessment of environmental impact is still a difficult task and as a result, it is difficult to determine the appropriate management improvement decisions, regarding this area. It is considered as necessary for the studied ecosystem to reach equilibrium, so that to launch an objective assessment of obtain results. For this reason, the project should be strengthened by continued monitoring and all the obtained data should be used to support the respective management decisions, concerning the protection and rehabilitation of this important natural (and protected) area.

4. CONCLUSIONS

This monitoring program constitutes a demonstrative action, applied in two coastal lagoons and it is going to act as an attempt for the future establishment of an Environmental Observatory in Thermaikos Gulf, especially regarding water quality issues. The developed monitoring protocol resulted to the production of necessary geospatial layers of Earth observation data, which in combination with the developed fusion algorithms, was able to generate (in almost real-time) an improved picture, regarding the ecological status of these ecosystems. In addition, the effective monitoring can provide the appropriate ecosystem services, which needed for the adaptive management, proposed for these habitat types, serving the relevant stakeholders. The developed technology (a fully Autonomous Water Telemetry Sensing System) constitutes an innovative approach of environmental monitoring, as any deviation from the control (base) level is mentioned, recorded and the incidents of pollution are detected in time, giving the respective alarm signal. Moreover, ATWSS aims to support with high confidence the validation and calibration procedures for all the air- and space-borne sensors, due to the meticulously recording of a vast quantity of detailed hyperspectral and spatio-temporal data.

REFERENCES

Airoldi L., Beck M.W., 2007. Loss, status and trends for coastal marine habitats of Europe. Oceanography and Marine Biology, 45: 345–405.

Bonin-Font F., Miquel Massot C., Codina G.O., 2016. Towards Visual Detection, Mapping and Quantification of Posidonia Oceanica using a Lightweight AUV. IFAC-Papers On Line 49-23: 500–505

Borja. A., Ranasinghe A., Weisberg S., 2009. Assessing ecological integrity in marine waters, using multiple indices and ecosystem components: challenges for the future. Marine Pollution Bulletin, 59: 1–4.

Caccia. M., 2006. Autonomous surface craft: prototypes and basic research issues. In Proc. 14th Mediterranean Conference on Control and Automation: 1–6.

Claudet J., Fraschetti S., 2010. Human –driven impacts on marine habitats: a regional meta-analysis in the Mediterranean Sea. Biological Conservation, 143(9): 2195–2206.

Dunbabin M., Grinham A., Udy J., 2009. An Autonomous Surface Vehicle for Water Quality Monitoring. Australasian Conference on Robotics and Automation (ACRA).

EEA, 2006. Priority Issues in the Mediterranean Environment. European Environment Agency, Copenhagen. Denmark.

Glasgow H.B., Burkholder J.A.M., Reed R.E., Lewitus A.J., Kleinman J.E., 2004. Real-time remote monitoring of water quality: a review of current applications, and advancements in sensor, telemetry, and computing technologies. Journal of Experimental Marine Biology and Ecology: 300: 409– 448.

UNEP/MAP, 2005. Review and Assessment of National Strategies for Sustainable Development in the Mediterranean Region. United Nations Environment Programme/Mediterranean Action Plan, Athens, Greece.