A story of two Lagoons - Observation and modelling of the impacted Venice (Italy) and pristine Razelm-Sinoe (Romania) Lagoons (Ref IAP2-18-75)

University of Stirling, Biological and Environmental Sciences
In partnership with University of Glasgow, Mathematics and Statistics. CASE Partner: Institute of Marine Sciences (CNR-ISMAR), Venice, Italy

Supervisory Team
- Prof Andrew Tyler, Dr Vagelis Spyrakos, Dr Peter Hunter, University of Stirling
- Prof Marian Scott, Dr Claire Miller, University of Glasgow
- Dr Georg Umgiesser, Dr Debora Bellafiore, CNR-ISMAR

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Overview
As with all transitional environments, lagoons fulfil pivotal roles in global-scale biogeochemical cycles being a nexus between the terrestrial and marine environments. This combination of factors drive the productivity of these ecosystems that are biodiversity hotspots with high conservation value. As a result, lagoons provide numerous ecosystems services that have tended to result in a long history of human settlement. Lagoons have therefore been subject to multiple conflicting societal demands and environmental pressures, including industrial, agricultural and domestic pollutants, as well as hydrological and morphological modifications. These pressures have been further compounded by the pressures of climate change. Lagoons are highly vulnerable to these natural and man-induced perturbations and may be characterised by having low threshold tipping points. However, our scientific understanding of these complex and dynamic environments is currently constrained by our inability to observe changes in ecosystem structure and functioning and their responses to environmental perturbation. This is a serious concern, as lagoons are likely to be highly sensitive to future environmental changes such as nutrient pollution, global sea level rise, changes in precipitation, storminess and changing patterns of land use. There is a need to establish new approaches for the collection, integration and assimilation of data from disparate sources including in situ monitoring programmes, Earth observation (EO) and couple these with hydrodynamic models for improved our understanding and the confident implementation of conservation and management solutions. This PhD will integrate these approaches to achieve a better understanding of the consequences of these perturbations of two contrasting lagoons in both time (decades, with one year simulations in each morphological configuration) and 3D space (from surface with EO products, and with depth through models, validate by in situ measurements).

To develop a better understanding and implement better management strategies of complex lagoon ecosystems, this PhD brings together state of the art Earth observation (EO) capability building on ESA’s sentinel programme to validate cutting edge hydrodynamic modelling. Together these will allow lagoon systems to be modelled to assess impacts on both past, present and future management scenarios to be evaluated in 3D space and time.

This PhD will focus on two contrasting lagoon systems: (i) the Razelm-Sinoe connected to the Danube and

Figure 1: MERIS monthly chlorophyll a concentrations at Razelm from Nov. 2005 to Jan. 2007.
impacted in the 1970s by being artificially isolated from the Black Sea by an engineered sand barrier to transform the lagoon into a freshwater system. At the same time the Razelm lagoon became a highly eutrophic environment. The lagoon now forms an important component of the Danube Delta Biosphere reserve; and (ii) the Venice lagoon, (UNESCO heritage site of inestimable value) with a deeply entrenched cultural history lasting for more than 1000 years, and probably the most well-known lagoon of the Mediterranean, with the largest wetland. In contrast to the Razelm, it is a heavily engineered lagoon with strong historical anthropogenic influence.

The EO capability allows the change in the optical water quality parameters (chlorophyll a, total suspended matter, colour dissolved organic matter) and temperature to be reconstructed at high temporal resolution using archived Envisat MERIS data (e.g. Figure 1) and near real time Sentinel 3 OLCI data and the spatial connectivity to sources of impact at high spatial resolution using Sentinel 2 MSI. This time frame provides data to validate the hydrodynamic models for a range of documented environmental change scenarios and reconstruct what has happened at depth, validated further by in-situ field campaigns.

The provision of well validated models for these two lagoons systems then provides a framework to assess the impact of different possible scenarios (natural and managed) that might impact on these lagoons in time (with each morphological configuration) and 3D space (from surface with EO products, to the water column on the whole system through models and validation procedure with in situ measurements). In the first instance modelling will encompass levels, currents, temperature and salinity (e.g. Figure 2), but may be developed to include other variables.

This project builds on the world leading EO capability that was developed during the NERC GloboLakes project (2012-2018; www.globolakes.ac.uk) and the expertise that has been brought together through the H2020 projects Danubius-RI (2016-2019; http://danubius-pp.eu and http://www.danubius-ri.eu) and MONOCLE (2018-2022: Multiscale Observation Networks for Optical monitoring of Coastal waters, Lakes and Estuaries) and CoatsObs (2017-2020; Commercial service platform for user-relevant coastal water monitoring services based on Earth observation). This will provide important areas of further research collaboration

**Methodology**

This PhD brings together three strands of cutting edge research in hydrodynamic modelling, Earth observation and in-situ validation, and data analytics.

**Hydrodynamic Modelling:** In the two study sites the SHYFEM model (Umgiesser et al., 2004), a finite element hydrodynamic 3D model, will be implemented. SHYFEM was developed at CNR-ISMAR (Venice) to investigate the dynamics in lagoons, coastal seas, estuaries and lakes. Beside its hydrodynamic core, this model has sediment transport, wave, water quality and ecological modules to fully characterize the system. The model has been applied to many transitional environments and coastal systems (Bellafiore & Umgiesser, 2010; De Pascalis et al., 2011; Ferrarin et al., 2010; Ghezzo et al., 2010; Umgiesser et al., 2014; Umgiesser et al., 2004) as well as on the Black Sea (Dinu et al. 2015).

**Earth observation:** Both Sentinel 2 and 3 along with archived MERIS data will be exploited to reconstruct and monitor change across both systems and in relation to the surrounding marine and freshwater environments (Tyler et al., 2016). In Venice Lagoon, for example, high resolution Sentinel 2 data will be used to establish the connectivity between the lagoon and Venice itself, the industrial inputs in addition to the Po river and the Mediterranean. In-situ characterisation of the biogeooptical properties (Riddick et al., 2015) and water leaving remote sensing reflectance will be used for algorithm validation including atmospheric correction (Spyrakos et al., 2017). The EO data coupled with depth profiles with in-situ radiometers will provide the validation for depth predictions from the SHYFEM model.

**Data analytics:** Cutting edge tools in environmental data analytics including downscaling, data fusion/linkage and functional data analysis will be investigated and applied for assimilation and fusion of the lagoon hydrodynamic model with the EO and insitu data. These data analytics approaches will be applied (and developed) in the R software environment to combine and validate these complex data sets, explore spatial and vertical variation of water quality parameters and their response to changing lagoon scenarios in a computationally efficient framework (Odonnell et al., 2015).

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Figure 2: Razelm Lagoon finite element grid (left). Example of model outputs, salinity (centre), residence time (right). Images from Dinu et al., 2015.
**Timeline**

The PhD student will split their time between the UK, University of Stirling and CNR-ISMAR, with additional time spent with partners at the University of Glasgow and at the Plymouth Marine Laboratory (PML).

- 0-9 months: Development of the research proposal review and science plan, site visits and initial training in research design, laboratory sample analysis, data analytics and EO. 9 month progress review.
- 16-22 months: EO data processing. Assessing change and impacts from drivers of change. 24-month progress review.
- 29-35. Final analysis
- 36-42. Write up and submission.

**Training & Skills**

The candidate will develop skills in model implementation, with specific competences in finite element tools. Each step of model implementation will be considered (creation of a computational grid, data treatment for initial, boundary conditions and forcings, output post-processing and analysis). Assimilation techniques are beyond the scope of this project but basic skills on how to use in an integrative manner EO products in modelling will be treated.

The candidate will also be trained in processing satellite image data and the application and tuning of algorithms for the accurate retrieval of in-water constituents, including atmospheric correction, and the development of processing chains. The candidate will be equipped with the know-how to perform accurate measurements of bio-optical properties and carry validation activities of remote sensing data and products for several available sensors. The measurements will include for example: spectral attenuation, absorption and scattering (Wetlabs AC-S; Wetlabs AC-9; Trios OSCAR); spectral backscattering (Wetlabs ECOBB3; HobiLabs Hydroscat; OBS); subsurface irradiance reflectance and above water-leaving reflectances (Satlantic HyperOCRs and HyperSAS; Trios Ramses). The applicant will be also trained in laboratory skills and analysis of bio-optical and radiometric data.

The student will present their findings annually within a postgraduate research symposium specific to Stirling, CNR, Glasgow and PML and international conferences. The student’s progress will be subject to annual progress reviews. All research students are members of Stirling’s **Institute of Advanced Studies** and are encouraged to attend seminars (that are particularly relevant to them in addition to the generic training skills provided by the IAPETUS DTP. Students also take advantage of the opportunities for networking with external visitors and students from other academic areas to promote interdisciplinarity.

**References & Further Reading**


**Further Information**

Prof Andrew Tyler, a.n.tyler@stir.ac.uk, +44 1786 467838.