Title of the project : New Raman spectroscopy-based optical microfibre pollutant sensors for monitoring water quality

Supervisors :
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Background :
Doñana National Park, located in the provinces of Huelva and Seville in Andalusia, southern Spain, is one of Europe's most ecologically significant areas. Declared a National Park in 1969 and reclassified in 1978, it covers 54,252 hectares, with a protected buffer zone of 74,279.95 hectares and a socio-economic influence area of over 200,000 hectares. The park is home to a unique landscape of marshes, clay plains, and dunes, which serve as a critical wetland habitat for migratory birds and a wide range of other species. Recognized as a UNESCO World Heritage Site, the park is of global importance for biodiversity conservation. However, Doñana is facing serious environmental challenges, largely due to anthropogenic pressures. The rapid expansion of intensive agriculture surrounding the park, particularly around the Doñana aquifer, has resulted in over-extraction of water and significant pesticide contamination. The nearby coastal town of Matalascañas also draws groundwater from the same source, further exacerbating water scarcity and pollution levels. The widespread use of agrochemicals, particularly pesticides, has led to serious ecological degradation. These chemicals, enter the water system through runoff, leaching, and filtration, contaminating the park's wetland ecosystems and harming its biodiversity. In addition to contaminants, eutrophication—an excess of nutrients, primarily nitrogen and phosphorus—presents another major threat to the park's aquatic ecosystems. Eutrophication leads to harmful algal blooms, which deplete oxygen levels in water, disrupt local ecosystems, and can produce toxins that pose serious risks to wildlife and human health. The combined effects of eutrophication and pesticide contamination have caused several episodes of mass mortality among birds and mammals, particularly due to the proliferation of toxic cyanobacteria. This situation has been worsened by climate change, which has altered precipitation patterns, leading to increased nutrient runoff and more frequent eutrophication events. Warmer temperatures accelerate algal growth, further depleting oxygen in already nutrient-rich waters.

Aims of the project :
Given these challenges, there is an urgent need for more effective monitoring and management strategies to safeguard the park's fragile ecosystems. This project aims to study the presence of pesticides and the impacts of eutrophication in Doñana's waters, with a focus on developing faster, more efficient methods for detecting and controlling contamination. Traditional laboratory methods, while accurate, are time-consuming and involve logistical challenges, such as sample degradation during transport. To overcome these limitations, the project explores the use of real-time monitoring tools and remote sensing technologies to provide timely data on water quality and algal bloom development. By integrating in-situ and satellite-based optical radiometric data, the study aims to establish an early-detection system for cyanobacterial blooms and other pollutants in Doñana's wetlands.
In this context, optical methods are very promising, and among them, Raman spectroscopy offers an effective tool for qualitative analysis and quantitative detection of pollutants for measuring water quality. The Raman spectrum of a substance gives the fingerprint of the species present and can provide information on their concentration, in a differentiated way. This technique presents many advantages: it is highly accurate and sensitive, non-destructive and requires minimal sample preparation. In addition, the use of optical fibres enables to perform remote sensing. At the Charles Fabry Laboratory (LCF), we have been working for several years on optical microfibres, which are silica optical fibres used for optical

telecommunications that we heat-stretch until their diameter is in the µm range. At these small diameters, the optical field that propagates through them has highly original properties. Among them, this field can present a very large fraction of light outside the microfibre, called the evanescent field. This field interacts strongly with the medium in which the microfibre is immersed. At the LCF, we have developed an optical microfibre drawing machine that enables us to produce microfibres of excellent optical quality in a controlled manner. Using these microfibres, we have carried out several world-first experimental demonstrations, such as the production of wavelength converters by Raman scattering in liquids immersing the microfibre, with near-optimal conversion efficiencies of the order of 60%.

In this PhD thesis, we propose to use Raman scattering in the evanescent field of a microfibre immersed in polluted water to detect the nature and concentration of the pollutants present. After a year and a half at LCF realizing a prototype of the optical system, the PhD student will spend one year at the Station to perform the first tests. The results will pave the way for the development of new sensors for specific pollutants in water and could subsequently be extended to the detection of pollutants in other media (gases, liquids).

Complementarities between supervisors :

S. Lebrun and J. Cobos met at the RamanFest conference organized by Horiba in Paris in 2024, in which they shared scientific common interests, leading them to build this project.

S. Lebrun is an associate professor at the LCF and has been working on nonlinear photonics, and more particularly in Raman diffusion in nano and micro structured fibers, such as optical nano/micro fibers since more than 20 years. She has supervised 3 PhD thesis, more than 15 master students and has coordinated an ANR project on nanofibers. She is general chair of the conference Nonlinear Photonics (Optica) and chair of a session on Optical fiber technology at the EOSAM conference. Her involvement rate in this project will be 50%.

J. Cobos is is the scientific coordinator of the technological infrastructure of the Large Scale Research Infrastructure of Doñana Biological Reserve (ICTS-RBD), he has been working from 1993 to 2008 in the area of the material sciences at JRC/EU Karlsruhe. He was head of unit at CIEMAT (Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas) a public research body assigned to the Ministry of Science and Innovation for more than 8 years. He is investigating the interrelationships between air pollution and global change, water pollutants in atmosphere interactions, in response to alterations and management, in different ecosystems. His scientific work is summarized in 78 scientific publications to date in the field of the waste management and pollution performance assessment and participation in book chapters and patents. He is/has participated actively as a member of executive boards and Spanish representative in international committees and in 19 international research programs. He has supervised 5 PhD thesis, and one in progress and has been involved in Young Researchers Education Program for Innovation.

Available ressources :

The LCF has all the equipment needed to carry out the optical system (Raman sensor, laser sources, fibre optics, spectrometer). The Scientific and technological infrastructure located in Doñana National Park for research purposes, include field-work facilities such as Wi-Fi network, field laboratories and housing. On the other hand the Biology and Chemistry Laboratories are a CISC infrastructure located in Seville equipped with the necessary modern equipment for conducting experimental activities and research programs together with climatic and germination chambers, greenhouse facilities and animal experimentation facilities.

« 3i » explanation :

This PhD project is a new interdisciplinary collaboration between two European laboratories, the LCF and The Doñana Biological Station at CSIC, both internationally recognized in their fields of expertise.

Both supervisors are strongly involved in international networks, which will give the results a wide international visibility. The beneficits of this research will open new solutions dedicated to the protection of ecosystems affecte by the global change.