Assessing the Spread of Invasive Mussels in Lake Neuchâtel as a Potential Threat to the Les Argilliez Heritage Site with Sentinel-2

Daniele Cerra, Peter Gege, Stefan Plattner
Remote Sensing Technology Institute
German Aerospace Center (DLR)
82234 Wessling, Germany
daniele.cerra@dlr.de, peter.gege@dlr.de, stefan.plattner@dlr.de

Fabien Langenegger, Sonia Wüthrich
Department of Archaeology
Office Patrimoine et Archéologie Neuchâtel (OPAN)
2068 Hauterive, Switzerland
Fabien.Langenegger@ne.ch, Sonia.Wuethrich@ne.ch

Jean-Christoph Roulet, Fabien Droz
Centre Suisse d'Électronique et Microtechnique (CSEM)
2002 Neuchâtel, Switzerland
jean-christophe.roulet@csem.ch, fabien.droz@csem.ch

***Abstract*—This paper provides insights into invasive Quagga mussel proliferation on the bottom of lakes around the Alps, considering potential threats to submerged cultural heritage sites such as Les Argilliez in lake Neuchâtel. By observing typical spectral characteristics of mussels and other water constituents and benthic materials, we report that this phenomenon could be observed in shallow waters and monitored over time using Earth Observation data. Preliminary results using Sentinel-2 data, partially validated through underwater surveys, indicate that the detection of these changes should rely on differences in the green portion of the spectrum.**

***Index Terms*—Inland waters, Earth Observation, invasive species, mussels, Sentinel-2.**

I. Introduction

Invasive freshwater quagga mussels (dreissena rostriformis bugensis) were observed across the bed of lake Neuchâtel for the first time in 2014. In the following years, the mussels have been spreading on the bottom of the lake towards northeast, with concentrated activity on the northern-western shore of the lake [1]. Recently, they have been observed close to the area of the heritage site of Les Argilliez which is protected by UNESCO as part of the World Heritage "Prehistoric Pile Dwellings around the Alps", a series of 111 small individual sites encompassing the remains of prehistoric pile-dwelling (or stilt house) settlements in and around the Alps built from around 5000 to 500 B.C. on the edges of lakes, rivers or wetlands [2]. The site is fully submerged and dates back to two Neolithic succesive villages built between 3841 and 3500 BC.

The effect of quagga mussels on cultural heritage sites has not been yet extensively studied, but this phenomenon could pose a threat to les Argilliez: mussels can stick to the pebbles but also to wood, damaging soft materials if removed, and alter the surrounding water characteristics and the whole lake ecosystem [3].

Underwater surveys have confirmed the phenomenon, but due to their cost, amount of surface covered, and time gaps between different observations, it would be desirable to derive information useful for their monitoring from optical Earth Observation data. Previous studies have analysed the impact of the similar species zebra mussels on the clarity of waters [4]. Regarding quagga mussels, the relation between their spread and water quality, patterns of water constituents concentration, and clarity has been discussed in [5]. Already ten years ago, changes introduced in aquatic ecosystems by both zebra and quagga mussels were observed in multiscale earth observation data in [6]. In this preliminary study, typical spectra of mussels and other materials both organic and non-organic contributing to the spectral information detected from space are analysed in order to assess the feasibility of this application and at which depths it could succeed. This work presents a first attempt at detecting the appearance of areas occupied by previously absent quagga mussels on lake bottoms by using multitemporal Sentinel-2 data.

II. Feasibility study

First, spectra of mixtures of mussels, typical sand samples and macrophytes have been simulated at different depths in order to assess if the detection of the mussels would be feasible at all, using the freely available software WASI [7]. Figure 1 reports the sample spectra used in the analysis, which in the simulation are mixed in different amounts and at different depths. Fig. 2 reports mixtures for mussels and sand and macrophytes and sand for very shallow (1 meter) and shallow waters (5 meters), respectively. Simulations show that, especially in the green range, mussels can be separated from sand in the bottom of inland waters, especially in the range from 500 to 600 nm, corresponding to the green range of emitted solar radiation. As depth increases, mixtures start to exhibit spectral features which appear more difficult to detect, separate and quantify. Therefore, a detection appears to be possible only in shallow waters.

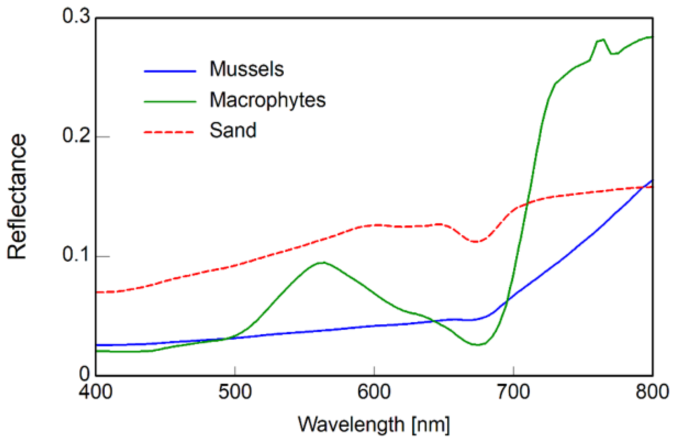


Fig. 1. Spectral library reporting typical reflectance spectra for mussels, macrophytes, and sand.

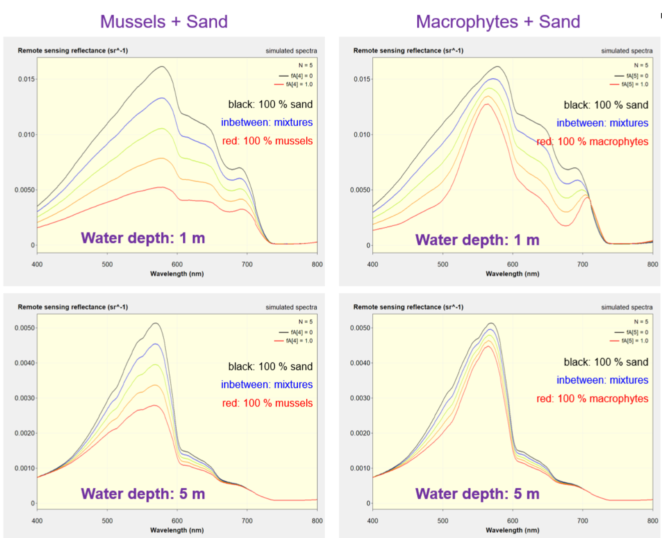


Fig. 2. Simulations of mixtures of different amounts of mussels and sand and macrophytes and sand within an image element for depths of 1 m and 5 m. For shallow waters, spectra differ especially in the green range of the measured backscattered radiation. As depth increases, for the case of 5 m it becomes more difficult to separate and detect materials in the bottom of inland waters.

III. Results

In order to assess the appearance of areas affected by spreading of zebra mussels, we first analysed another site affected by this phenomenon in the proximities of Unteruhldingen in Lake Constance, where some validation data are available. A presence of the mussels was not documented here before 2019, with georeferenced reference data for the extent of the mussels in spring 2022 obtained by underwater assessment and readily available in vectorized form. Monthly Sentinel-2 composites obtained in a Google Earth Engine environment by selecting median values for cloud-free images acquired during the months of April 2018 and 2022 are reported as true color combinations in Figs. 3 (a) and (b), respectively. Here, the area where mussels were found in the 2022 underwater survey is outlined in red. Visual inspection confirms a correlation between the decrease of reflectance in the spectrum, especially evident in the green, and the main areas affected by this phenomenon. In order to highlight the results, Fig. 3 (c) reports the ratio between the green bands in these two images, overlaid on the 2022 median image, with values equal to 1 (no change) associated in the colormap to blue and decrease of 50% in green reflectance reported in white. A mask is applied in order to remove deep waters, where the band ratio is not meaningful. The correlation between the presence of quagga mussels and decrease in green reflectance appears evident in the results.

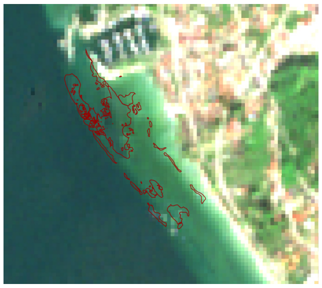
Subsequently, the area around les Argilliez has been analysed, with special attention to shallow waters near Concise, approximately 5 km south of the heritage site, where visits on site carried out by OPAN suggest that mussels could have been recently spreading. Underwater surveys have documented the appearance of mussels in latest years, as confirmed by underwater photographs in this area acquired in 2017 (no mussels visible) and 2022 (presence of mussels is evident). The photos are reported in Fig. 4. As in the Unteruhldingen case, Fig. 5 shows a rendering of Sentinel-2 image aggregates computing the median of cloud-free images from the months of April 2018 and 2022, respectively, in which the area where mussels are expected to have spread appears darker also here in the green range of the spectrum, according to the dark spectra considered in our simulation in Fig. 2. The ratio of the green bands in these two images is overlaid to the 2022 image composite in Fig. 6, with largest changes depicted in red, confirming the extent of the phenomenon and providing a first identification of critical areas. This case of study will be validated on site in the future with an underwater survey planned for the first months of 2024.

IV. Conclusions

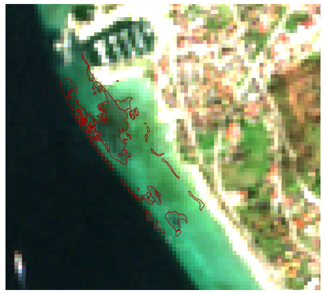
Quagga mussels emerge as potential threats to submerged cultural heritage sites, with their capacity to adhere to pebbles and wood raising concerns about damage to soft materials, and the unknown long-term changes implied in terms of changes to the water constituents and impact on the lake ecosystem. Conservation strategies must consider these implications to ensure the preservation of cultural heritage artifacts in the lake.

The study highlights the utility of remote sensing data, particularly from Sentinel-2, in monitoring the spread of these mussels in shallow waters. Their spectral characteristics may provide insights for understanding the spatial distribution and dynamics of mussel infestations across the lake.

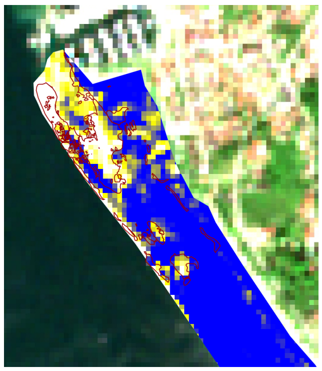
However, challenges arise in spectral separability, particularly in deeper waters, where the detection becomes harder as depth increases. Further studies are warranted to verify spectral separability and assess the true impact of Quagga



(a) 2018

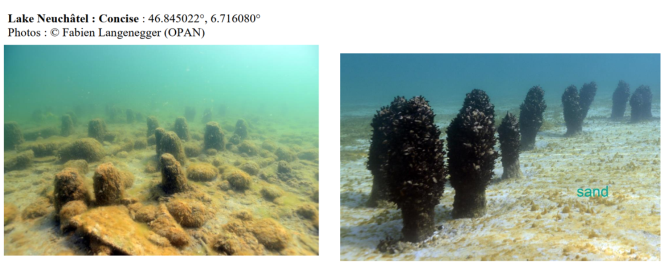


(b) 2022



(c) ratio

Fig. 3. True color representation of Sentinel-2 image composites for the months of April 2018 (a) and April 2022 (b), with extension of the quagga mussels documented in April 2022 with underwater survey outlined in red. The decrease in reflectance in the green portion of the spectrum well correlates with the spreading of this phenonemon, and is highlighted by the ratio between the green bands of the two images in (c), with deep waters masked out, with blue corresponding to no change and white to a decrease of around 50%.



(a) Concise, 2017

(b) Concise, 2022

Fig. 4. Underwater photographs in the area of Concise, few km away from Les Argilliez site. The phenomenon of quagga mussels spreading after five years is evident.

mussel spread, especially considering conflicting reports on their potential as protective barriers or sources of material damage to submerged cultural heritage sites, including the Les Argilliez site. Ongoing research should further assess spectral separability and understand the implications for the preservation of underwater archaeological structures, guiding conservation strategies and management decisions for submerged cultural heritage sites which may be affected by this phenomenon. Furthermore, it should be assessed if the analysis of spaceborne hyperspectral data (e.g. DESIS [8], EnMAP [9]) may increase the separability of mussels in shallow waters, in spite of the decrease in spatial resolution.

Fig. 5. True color representation of Sentinel-2 image composites for the months of April 2018 (a) and April 2022 (b), suggesting a proliferation of quagga mussels in the area exhibiting decreased reflectance in the green portion of the spectrum.

Fig. 6. Anomalous values for the ratio of reflectance in the green portion of the spectrum between the two images reported in Fig. 5 for the area of Concise. Areas exhibiting a high ratio are reported in red and could imply a larger concentration of mussels.

V. Acknowledgments

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