Efficiency of using satellite images to assess past and future changes of aquatic vegetation in rivers

Efficacité de l'utilisation d'images satellites pour évaluer les changements passés et futurs de la végétation aquatique en rivière

Léo Rasse[1], Julien Godfroy[2], Géraldine Nogaro[3], Florian Cordier[3], Sara Puijalon*[1], Hervé Piégay*[4] | *co-leadership

leo.rasse@univ-lyon1.fr ; julien.godfroy@inrae.fr ; geraldine.nogaro@edf.fr ; florian.cordier@edf.fr ; sara.puijalon@univ-lyon1.fr ; herve.piegay@ens-lyon.fr

[1]Universite Claude Bernard Lyon 1, LEHNA UMR 5023, CNRS, ENTPE, F-69622, Villeurbanne, France; [2]Université Grenoble Alpes, INRAE, LESSEM, St-Martind'Hères, France; [3]EDF Research and Development, National Hydraulics and Environment Laboratory (LHNE), 6 quai Watier, 78401 Chatou, France; [4]University of Lyon, ENS Lyon, CNRS, UMR 5600 EVS, Lyon, France.

RÉSUMÉ

Depuis plusieurs décennies, l'acquisition d'images satellites a considérablement accéléré le suivi de la végétation, mais leur utilisation reste limitée en milieu aquatique du fait des interférences induites par la colonne d'eau. L'objectif de cette étude était d'analyser si les images issues de nouvelles campagnes de données satellites à haute résolution spatiale et temporelle peuvent être utilisées pour suivre la végétation aquatique. Pour cela, des images aériennes à très haute résolution spatiale (15-25 cm) ont été utilisées comme données de validation et les images satellites Planet (3 m, revisite journalière, planet.com) acquises à ± 15 jours des images de références ont été téléchargées. Pour chaque image Planet, un indice de végétation basé sur la réflectance dans le vert et dans le proche-infrarouge, le GNDVI, a été calculé afin de tester si la végétation aquatique et l'eau peuvent être différenciées sur le plan spectral. Les premiers résultats ont montré que les valeurs de GNDVI étaient différentes entre l'eau et la végétation mais avec un seuil de distinction des deux classes variable entre les images. Ces résultats indiquent qu'un seuil unique ne peut donc pas être appliqué à l'ensemble des images pour distinguer la végétation aquatique de l'eau. Les défis futurs consisteront à tester si des méthodes statistiques peuvent être utilisées pour distinguer la végétation aquatique de l'eau sans avoir recours à des observations de terrain. Ces avancées seraient particulièrement utiles pour suivre la dynamique de la végétation aquatique et soutenir les gestionnaires dans la prise de décision, ainsi que dans les efforts de conservation et restauration des cours d'eau.

ABSTRACT

Since several decades, the acquisition of satellite images has considerably accelerated the monitoring of vegetation, but their use remains limited in aquatic environments due the interferences induced by the water column. The aim of this study was to analyse whether data from recent high spatial and temporal resolution satellite campaign could be used to monitor aquatic vegetation. For that purpose, very high spatial resolution images (15-25cm) were used as validation data and Planet satellite images (3m, daily acquisition, planet.com) acquired within ± 15 days of the reference images were downloaded. For each Planet image, a vegetation index based on reflectance in the green and near infra-red spectra, the GNDVI, was calculated to test whether aquatic vegetation and water can be differentiated spectrally. First results showed that GNDVI values are different between water and vegetation but with contrasting thresholds for distinguishing the two classes among images. These results indicate that a single threshold cannot be applied to all images to distinguish aquatic vegetation from water. Future challenges will consist in testing whether statistical methods can be used to distinguish aquatic vegetation from water without referring to field observations. These advances would be particularly useful for monitoring the dynamics of aquatic vegetation and supporting managers in their decision-making, and in aquatic ecosystems conservation, and restoration efforts.

KEYWORDS

Dynamiques spatio-temporelles, images satellites Planet, Rhône, télédétection, végétation aquatique

Planet satellite images, remote sensing, Rhône River, spatio-temporal dynamics, submerged aquatic vegetation

1 INTRODUCTION

Aquatic vegetation plays a key role in the functioning of aquatic ecosystems[1], but can also interfere with human activities[2]. In rivers, the spatio-temporal dynamics of aquatic vegetation is strongly influenced by hydro-geomorphological conditions[2,3], which can be impacted by climate change, flow regulation, and hydro-morpho-ecological restoration actions. Monitoring changes in aquatic vegetation and predicting the effects of hydro-geomorphological shifts represent a key challenge to support and guide stakeholders. Traditional field surveys used to monitor aquatic vegetation are limited to small spatial and temporal scales and cannot be used to reconstruct past trajectories. Since the late 20th century, the availability of satellite images acquired both in the past or in real-time provides new opportunities for monitoring aquatic vegetation and understanding ecosystem functioning. However, these data remain underexploited for aquatic vegetation relatively to terrestrial one due to the coarse spatial resolution and the scattering, reflectance and absorption of light induced by the water surface and column[4] that limit their potential for mapping aquatic vegetation. This study aims to overpass these limitations to test if nanosatellites such as Planet (planet.com) with a fairly high spatial and temporal resolution (3m, daily acquisition) can be used to assess past and future changes of aquatic vegetation in rivers. Specifically, we present here the results of the first tests which aimed to investigate whether large stands of aquatic vegetation can be spectrally differentiated from water. Large stands correspond to vegetated areas that are several hundred of meters long and several dozens of meters wide, composed of one or multiple plant species (Fig 1).

Figure 1: Aquatic plant stand located on the Rhône River. Photo credit: Sara Puijalon, the 4th July 2023.

2 METHODOLOGY

This study was conducted on three aquatic plant stands located on the Rhône River near the city of Cruas. For each stand, two types of images were used:

- Aerial images acquired once per year in summer 2017, 2018, 2019 and 2023. Due to their high spatial resolution (15-25cm), aquatic plant stands were clearly delineable from water, making these images effective as validation data.
- Planet satellite images, with a coarser spatial resolution (3m), but acquired daily since 2017.

For each stand, all cloud-free Planet images taken within ± 15 days of the aerial image acquisition were downloaded and pixels were defined as aquatic vegetation or water based on the visual interpretation of aerial images. On each Planet image, the GNDVI spectral index was calculated with the following formula:

$$GNDVI = \frac{\rho NIR - \rho G}{\rho NIR + \rho G} \quad (1),$$

where ρNIR and ρG are the reflectance in the near-infrared and green spectral bands, respectively. The GNDVI is sensitive to chlorophyll and was used instead of the NDVI spectral index widely applied in terrestrial environments as the green light is less absorbed by the water column compared to the red-light[4].

To test whether aquatic vegetation was spectrally discernible from water, we first used the distribution of GNDVI values of both classes to apply threshold based on visual interpretation. For each Planet image, aquatic vegetation was defined as pixels for which the GNDVI was higher than the 10th percentile of the GNDVI of aquatic vegetation, the remaining pixels being classified as water. As the GNDVI of aquatic vegetation and water can vary from one image to another due to changes in environmental conditions (*e.g.* water height and turbidity), a frequency map was calculated with the following formula to remove the noise induced by such changes:

$$\text{Frequency} = \frac{x}{y} \quad (2),$$

where x represents the number of times a pixel has been classified as aquatic vegetation and y is the total number of Planet images downloaded within the ± 15 days of the aerial image acquisition. Aquatic vegetation was then defined as the pixels with a frequency higher or equal to 0.75, with the remaining pixels classified as water. The producer and user accuracies were computed to assess the accuracy of all classifications. The former corresponds to the accuracy at which the observed classes are correctly classified as such, while the latter corresponds to the accuracy at which classified classes are really observed as such.

3 RESULTS AND MAIN CONCLUSIONS

Visual interpretations of the aerial images revealed that the stands were sparse and consisted of aquatic plants which did not reach the water surface in 2018, whereas the opposite pattern was observed in 2017, 2019 and 2023. Consistent with these observations, our results showed that the GNDVI of aquatic vegetation was higher than that of the water, with smaller differences of values observed in 2018 compared to other years (Table 1). Moreover, while the producer accuracy was relatively high for both classes on all stands and years, the user accuracy of the aquatic vegetation was high in 2017, 2019 and 2023 and low in 2018 (Fig 2,3), suggesting that the distinction of aquatic vegetation from water can be limited when using a single GNDVI threshold.

Table 1: Results of the linear mixed effects models performed on each year. Each model includes the GNDVI as the response variable, the class (aquatic vegetation or water) as the fixed effect and the date and the stand as random effects.

Year	Mean GNDVI aquatic vegetation	Mean GNDVI water	Difference of mean GNDVI values	p-value
2017	0.269	0.1393	0.1297	< 0.001
2018	0.1773	0.1297	0.0476	< 0.001
2019	0.2584	0.094	0.1644	< 0.001
2023	0.0882	-0.0892	0.1774	< 0.001

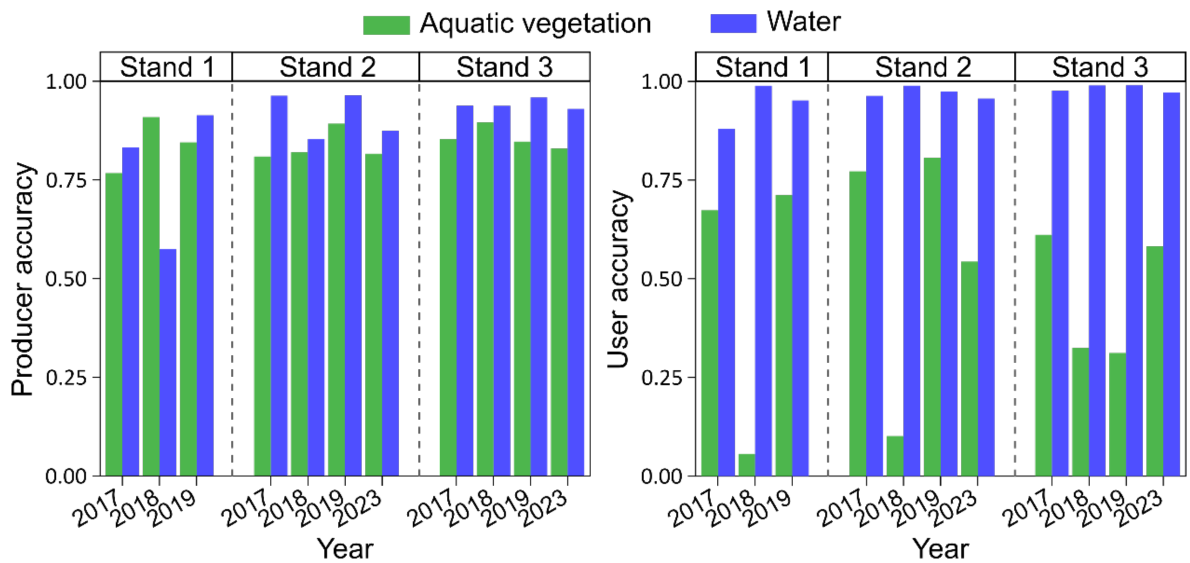

Figure 2: Producer and user accuracies of aquatic vegetation and water on the three aquatic plant stands in 2017, 2018, 2019 and 2023.

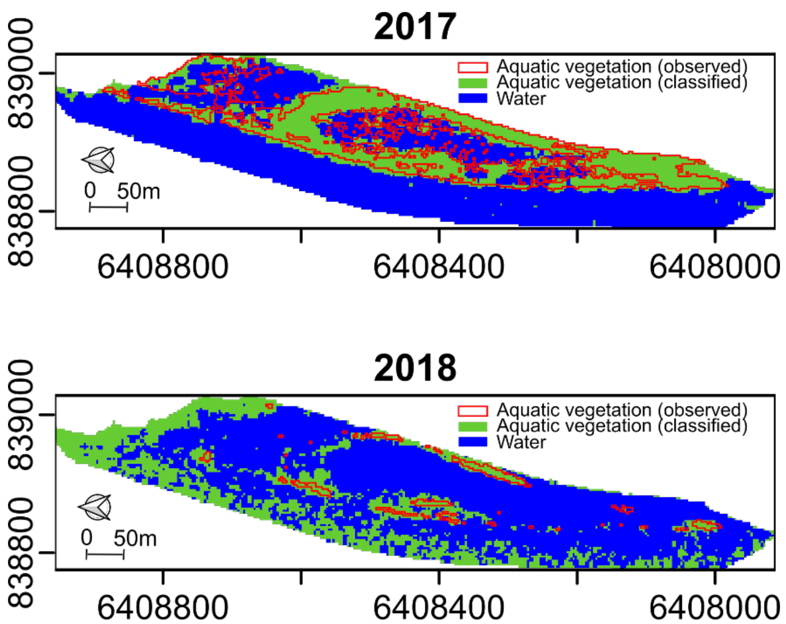

Figure 3: Examples of classifications obtained on the stand 1 in 2017 and 2018.

Our preliminary results show that both aquatic vegetation and water can be distinguished with the GNDVI calculated on Planet satellite images. However, a single GNDVI threshold cannot be applied to classify all Planet images as it varies according to the density of aquatic vegetation and the size of plants (2018 *vs* 2017, 2019 and 2023). Future challenges will be to test whether statistical analyses can be used to separate dates with sparse vegetation from dates with dense vegetation and to determine a GNDVI threshold that can be used without referring to observed high resolution airborne data. Such advances would be particularly useful in assessing past and future changes in aquatic vegetation, in understanding the response of aquatic vegetation to different hydro-geomorphological conditions and therefore to support managers in decision-making, and in aquatic ecosystems conservation and restoration efforts.

4 LIST OF REFERENCES

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