Floating Weed Manager

Floating Weed Manager

Final Report

EUROPEAN SPACE AGENCY CONTRACT REPORT

The work described in this report was done under ESA contract. Responsibility for the contents resides in the author or organisation that prepared it.

Prepared by: Laurence Carvalho[1], Emma Tebbs[2], Henry Thompson[2], Charlie Stratford[1], Anne Dobel[1], France Gerard[1], Gemma Nash[2] and Philip Taylor[1]

[1]UK Centre for Ecology & Hydrology, [2]Kings College London

Reference: FWM_Feasibility Study – Final Report_20210425_Final

Issue/Revision: Issue 1.0

Date of Issue: 21st April 2021

Status: Final

Contents

1 Introduction

1.1 Programmatic Framework

Floating Weed Manager is a surveillance and monitoring service of invasive species of aquatic floating-leaved plants ("Floating Weeds") which can cause social and economic disruption to communities living and working around impacted lakes and reservoirs. It combines radar and optical satellite EO data to provide weekly data and maps of weed coverage to support surveillance and monitoring of the distribution and magnitude of weed populations and consequently supports more effective targeting of weed control programmes (Figure 1).

Figure 1: Floating Weed Manager: Service Infographic

1.2 Project Team

The Project team is comprised of technical and business development staff from the UK Centre for Ecology & Hydrology (UKCEH) and technical staff from King's College London (KCL).

UKCEH is a not-for-profit Company Limited by Guarantee with charitable status. It has an enterprise arm that can undertake commercial work. UKCEH has about 450 employees and an overall annual turnover of just over €45 million.

King's College London (KCL) is a public research university located in London, UK. It has 8,500 employees and an overall annual turnover of just over €800 million.

1.3 Background and Motivation

Floating-leaved aquatic weeds can rapidly clog up lakes, reservoirs and navigation canals, leading to major economic impacts for businesses, fisheries and leisure activities. Sectors affected include navigation, water supply, hydropower and biodiversity conservation. The economic cost of managing invasive aquatic species and the damage they cause has been increasing in recent years and is estimated to be about $20 billion annually in 2020 (Cuthbert et al., 2021). Three invasive floating weeds included in this cost estimate, water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*) and Kariba weed (*Salvinia molesta*), are estimated to cost approximately 1 billion annually (Cuthbert et al., 2021). The growth and spread of invasive floating weeds is a particular problem in freshwaters in tropical and sub-tropical regions across the globe, with water hyacinth being one of the most widespread problem species (Theuria, 2013; Figure 2) and one of the top ten most costly invasive aquatic species in relation to damage and management costs (Cuthbert et al., 2021).

Weed eradication is considered impossible in many countries, so weed management focuses on suppression (typically using herbicides or biological control agents, such as plant-specific weevils) and containment. For this, a monitoring or surveillance service is needed that can frequently assess the distribution and coverage of floating aquatic weeds for their control programmes. As free-floating weeds can move rapidly with winds, providing a frequent and complete picture of their coverage across the whole waterbody surface is key to inform boat access and target weed control programmes. Frequent updates also enable a surveillance service across large areas to provide early warning of weed problems to enable control programmes to act before invasive plant populations get too established.

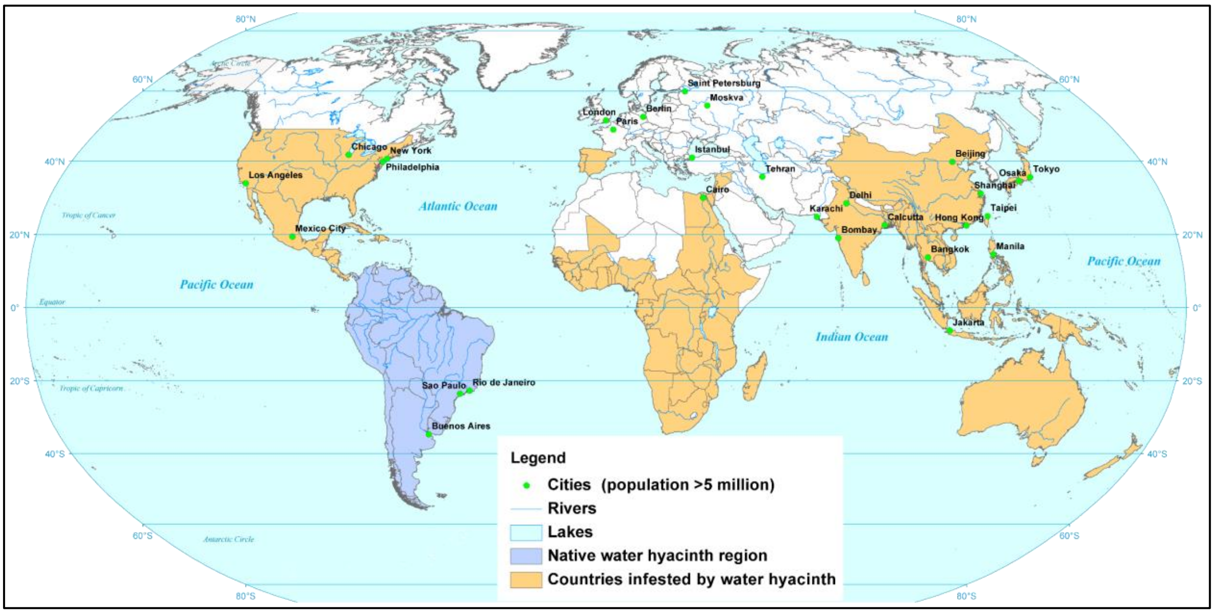

Figure 2: Global distribution of water hyacinth. Source: Theuria (2013) redrawn from Téllez et al., (2008).

Currently, surveys of floating weeds are carried out from boats or helicopters. Weed management is a continuous ongoing requirement that costs a large amount of money to undertake. A large proportion of this money is in surveillance and monitoring of weed coverage. Similarly large amounts have been spent monitoring the East African great lakes to support weed management and control programmes.

1.4 Objective of the Feasibility Study

The objective of this ESA Feasibility Study is to investigate the technical feasibility and economic viability of a Floating Weed Manager service. The service will supply weekly maps and metrics of free-floating weeds using a combination of radar and optical images from ESA Sentinel satellites. Floating Weed Manager will be a web monitoring and surveillance service that offers customers across the globe a range of products to provide actionable data to support enhanced weed monitoring and management programmes.

2 Customers & Users

Many countries across the tropics and sub-tropics are economically impacted by invasive floating weeds (Figure 2), with potential problems reported across high (8 countries), upper middle (12 countries), lower middle (16 countries) and low (8 countries) income countries across the globe (CABI, 2019). Of these we have focused our feasibility study to evaluate representative customers across different regions to represent different types of markets (World Bank income categories).

Specifically, we have focused on the USA (high income), Australia (high income), South Africa (Upper middle income) and Kenya (Lower middle income)

2.1 Customer Segment 1: Government agencies managing large weed control programmes

Segment 1 customers include government agencies and potentially other organisations that are obliged by legislation, as well as necessity, to control floating weeds over large areas. Customers we have engaged with in the feasibility study include our Champion Customer, the United States Army Corps of Engineers (USACE) and other agencies in the USA: South Florida Water Management District (SFWMD), Florida Fish and Wildlife Conservation Commission (FWC); Agriculture Victoria (Victoria State Government) and Biosecurity Queensland (Queensland State Government) in Australia and the Kenyan Marine and Fisheries Research Institute (KMFRI).

Customers in the USA need a monitoring or surveillance service that can frequently assess the distribution and coverage of floating aquatic weeds to target their control measures. The system needs to be more cost-effective than the current approaches used, typically boat and aerial surveys. Customers also need up-to-date information to make their weed control programmes more cost-effective by better targeting weed populations before they get too big. Monitoring changing weed distributions to inform navigation and fishing is the main issue in the Winam Gulf in Lake Victoria, Kenya. Whereas in Australia, the emphasis is more on surveillance to identify and eradicate weeds before they become a large problem.

Spatial coverage across large landscapes and sufficient frequency of monitoring and surveillance is the key problem for customers in all three regions. For example, it takes USACE 1 month to survey 20 sectors in Lake Okeechobee (1890 km^2), sampling only a small fraction of the lake (approximately 10-100 sampling points per 8 km^2 in shoreline zones only). In Australia, there are 1000's of km of river length and irrigation drainage channels (10-50 m wide) in relatively inaccessible areas to maintain surveillance on. Weed coverage in Lake Victoria (69,000 km^2) is very dynamic due to winds re-distributing weed over large areas. Due to the vast areas involved, satellite EO has the potential to provide a very cost-effective approach for customers monitoring floating aquatic weeds over large areas in all these regions.

2.2 Customer Segment 2: consultancies undertaking weed programmes

Segment 2 customers include consultancy businesses and other customers that undertake floating weed control programmes for government ministries, agencies or businesses. Customers we have engaged with in the feasibility project include: the Centre for Biological Control (CBC), Rhodes University who manage weed control programmes for the South African government; the Centre for Agriculture and Bioscience International (CABI) who manage weed control programmes in Africa, especially East and Southern Africa. As for customer segment 1, these customers need frequent, up-to-date maps of weed coverage for specific waterbodies, or regions of interest. The service could provide more-up-to-date maps than they currently have, making their control programmes more cost-effective.

We anticipate that these customers will be more relevant in more challenging markets (low income countries) where direct funding from government agencies is not always available. Their established contacts with governments working alongside development agencies and the World Bank may potentially provide important partnership routes for delivering our service.

2.3 Customer Segment 3: businesses/NGOs impacted by weed problems

These customers include businesses (e.g. water supply companies) and other customers (e.g. NGOs) that either undertake floating weed control programmes or require information on weed coverage and distribution for their business to operate profitably. As for customer segment 1, they need frequent up-to-date maps of weed coverage for specific waterbodies or regions of interest. The service could provide actionable data and maps to inform their business operations.

Customers we have engaged with in the feasibility study include Umgeni Water, a water supply company in South Africa who manage weed control programmes in their reservoirs and their catchments. We have also engaged with Save the Olifants River, a NGO in South Africa, who manage weed control programmes in the river to protect native biodiversity.

3 Service Offer & Value Proposition

The final service offer and value proposition were finalised and agreed with potential customers through a series of regional online workshops and an online user survey.

The service offer and value proposition are the same for all three customer segments based on their need for the same user requirements, including the following key aspects:

- Cloud-free composite maps of floating weed cover at 10 x 10 m resolution typically feasible every 1 – 2 weeks depending on seasonal cloud cover in the region.
- Summary statistics of floating weed cover for user-specified regions.
- Time series of floating weed coverage for regions of interest.
- Analysis of weed cover changes.
- An online web portal to access and download current and past maps, time series data and summary metrics.
- An average accuracy of 80% or better on floating weed maps.

Additional service components could include the following features, but need further validation in a Demonstration Project as ground truth data were unavailable during the feasibility study:

- Maps and metrics that distinguish different species of floating plants
- Maps and metrics of floating weed plant health
- Maps and metrics of water hyacinth flowering

Value Proposition

The service will provide value for customers in their Aquatic Plant Management Programmes, by supplying a key user need: up-to-date maps of floating weed coverage and related statistics. The cost of these products, obtained from satellite data, is cheaper than collected through traditional boat and aerial surveys (initial estimates circa half the price). The value is also higher as our service provides more comprehensive surveys of the whole extent of a waterbody, and at a higher repeat frequency than their current operations. Customers also save money as less time is spent on weed control programmes. This is because the increased spatial and temporal coverage of our satellite products allow weeds to be targeted more efficiently.

4 System Concept

The system architecture for the Floating Weed Manager service is illustrated in Figure 3.The system will consist of the following elements:

1. Satellite EO imagery: Sentinel-1 Level 1 processed radar imagery and Sentinel-2 Level 2A processed optical imagery, downloaded from Copernicus Data Hub. Potential addition of commercial PlanetScope imagery, which can be accessed via several pricing options, for pre-defined locations, by hectare or with global coverage.

2. Computing platform to run the processing chain. Options include a commercial cloud service or in-house processing and storage, with three options to be trialled in the demonstration project.
3. Processing Chain: Processing of satellite imagery to produce floating weed maps and total macrophyte cover maps. Stages include lake boundary definition, pre-processing (cloud masking and image smoothing), calculation of spectral indices, classification and thresholding, production of classified maps and change detection maps.
4. Aquatic Weed Mapping Algorithms: Algorithms developed to classify floating weed from satellite imagery based on a database of ground truth data.
5. Service Website: Web portal allowing users to view maps, timeseries and summary statistics for user-defined regions of interest. Users can access historic data and view change over time. All data is available for download from the website. An API will deliver maps and metadata from the processing chain to the service website. Users will also have the option of accessing data directly through the API to integrate data into their existing systems.

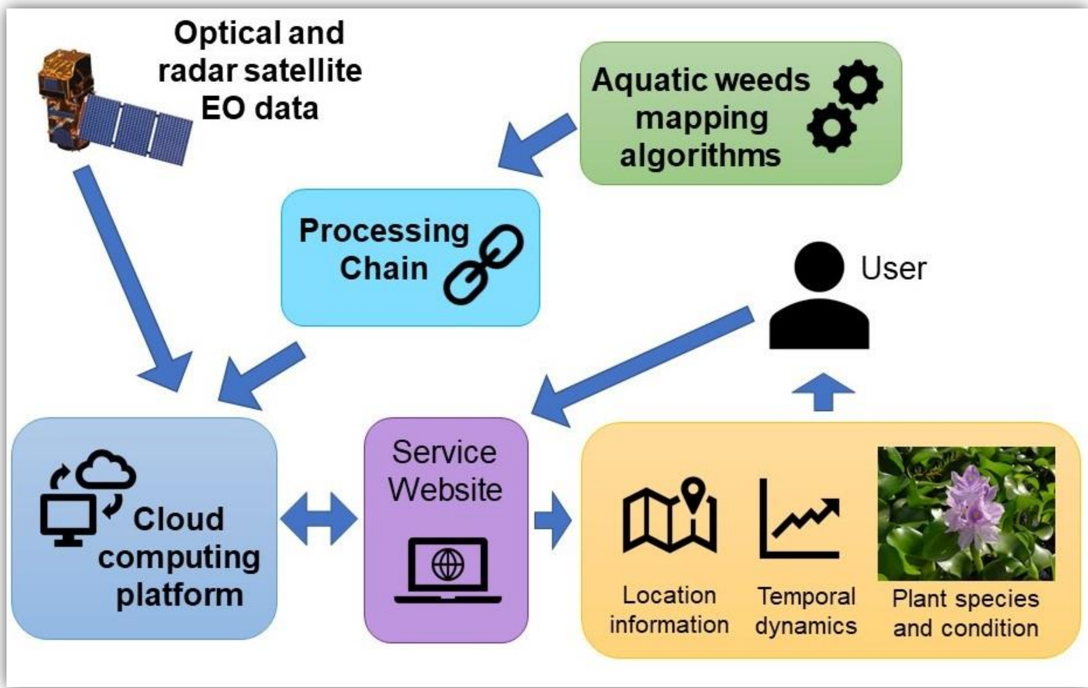

Figure 3. A high-level diagram of the Floating Weed Manager system / service showing the key attributes and key building blocks and the main interfaces.

Radar data will be used to deliver dependable macrophyte cover maps, unaffected by cloud cover, every 12 days. Optical data will supplement that to provide a higher frequency of survey and differentiate floating weed species from emergent vegetation. The Service will create a processing chain that delivers products on the website less than two days from receiving the satellite data.

5 Proof of Concept

5.1 Critical Aspects of the Service/System

The PoC focused primarily on validation of technological assumptions as these were of most interest to customers. Based on the survey of user requirements, a set of KPIs and critical assumptions were defined.

Technical Feasibility Assumptions:

Product Accuracy:

- Sentinel-2 can map floating weeds with a mean accuracy of 80% or better
- Sentinel-1 can map macrophyte cover with a mean accuracy of 80% or better

Generalisability of Algorithms:

- Algorithms robust to range of conditions, e.g. seasonal differences and geographic location

Latency:

- Up-to-date weed maps can be generated with a latency of <48 hours

Frequency of Imagery:

- S1 radar and S2 optical data can together provide maps of floating weeds at a minimum monthly frequency, ideally weekly to fortnightly

Spatial resolution:

- High spatial resolution (20 m or better) to identify small patches of floating weed amongst emergent vegetation.

5.2 Overview of the Proof of Concept

The purpose of the PoC was to demonstrate to customers that we can produce the service they are interested in. It was also to make clear that we have the technical capability and the track record as organisations that deliver. The PoC was designed to stimulate discussion with the customers to encourage co-design of the product, especially the web portal front end. The critical elements to be proven in the PoC were the technical aspects, as those were the ones that customers were most interested in.

Development of the PoC within this project included:

- Demo of existing CEH data portal websites to customers to illustrate what could be possible.
- Demonstration that we can produce macrophyte cover and floating weed maps using Senitel-1 radar and Sentinel-2 optical imagery with a level of accuracy and latency that is acceptable to user requirements.
- Basic demo of page layouts and potential content for the product web portal. Produce a mock-up of what the final web portal could look like, showing maps, time-series and key statistics to see whether this meets users' needs.

The PoC was carried out in two phases:

Phase 1 - Proof of Concept definition:

- Initial demonstration of existing data portals and our ability to produce maps of water hyacinth from RADAR and optical imagery.
- Collect feedback from customers on these and gather information on the critical elements and quantifiable success criteria for the final PoC.

Our starting point was definition of the critical elements for the PoC, informed by the service KPIs identified in the initial Task 1 customer workshops and follow-on surveys and the technical feasibility assessment of Task 2. Quantitative assessment criteria were also identified.

Phase 2 - Implementation and validation of final PoC:

- Develop PoC based on identified critical elements.
- Adapt existing algorithms and processing chains to meet requirements.
- Conduct ground truthing of satellite maps to confirm accuracy.
- Refine web portal layout.
- Present final PoC and validation results to customers/users.
- Gather feedback on the PoC from customers.

The algorithms and processing chains refined in Task 2 were applied to generate PoC vegetation cover and floating weed maps. A key proof of concept is that we can demonstrate that the maps have an accuracy that meets user requirements. This was achieved by validating the maps with field data analysed in Task 2. The final PoC was then circulated to customers electronically along with a user survey for them to comment on (Appendix 1 in final PoC report). We also held follow up online workshops with customers to gather additional feedback on the PoC. Accuracy is a primary concern for users, therefore rigorous validation of the maps was carried out.

5.3 Key Results of the Proof of Concept

The PoC demonstrated that we can deliver a service that meets customers' needs. Through a series of ten workshops and meetings with customers/users from the US, Kenya, South Africa and Australia we have co-designed a service that meets user requirements and will improve their weed monitoring capabilities. Products were developed based on feedback gathered during workshops and through user surveys.

The processing chain, for processing Sentinel-1 and Sentinel-2 imagery, and the weed mapping algorithms were refined to meet users' needs. Scripts were written using Google Earth Engine's JavaScript API to implement this processing chain and to apply weed mapping algorithms. Since the ability to produce accurate maps was a primary concern for customers, extensive work was carried out to compile a database of ground-based observations that could then be used to train and validate the satellite algorithms. Customers, particularly those in the US, collaborated closely with us on these validation activities, providing us with existing ground datasets and conducting dedicated field visits using drones to generate large quantities of ground data points. The use of drones for collecting ground data was a game changer as it generated large volumes of high-quality data in comparison to the boat surveys.

The weed mapping algorithms utilised random forest classification. This is a supervised classification method so requires a training step. However, the intention is that this training will be carried out once for each region and the trained classifier can then be applied to any lake in that region for any season. To achieve this, algorithms must be trained using a dataset that is representative of seasonal and geographical variability, including atmospheric variability and differences in plant health and phenology. This is important for ensuring that the algorithms are robust and can produce accurate maps across different water bodies and different times of year.

The PoC study has demonstrated that maps of aquatic vegetation and floating weeds can be generated with sufficient accuracy to meet user requirements. Our analysis confirmed that it was possible to produced weed cover maps with a mean accuracy of 80% when validated against ground data. For a single image of Lake Okeechobee in May 2019, Sentinel-2 floating weed maps had a mean accuracy of

86% (Figure 3). A second model trained and validated using 1057 ground data points from 13 lakes in Florida, between 2019-2020 was able to map floating weeds with a mean overall accuracy of 84%.

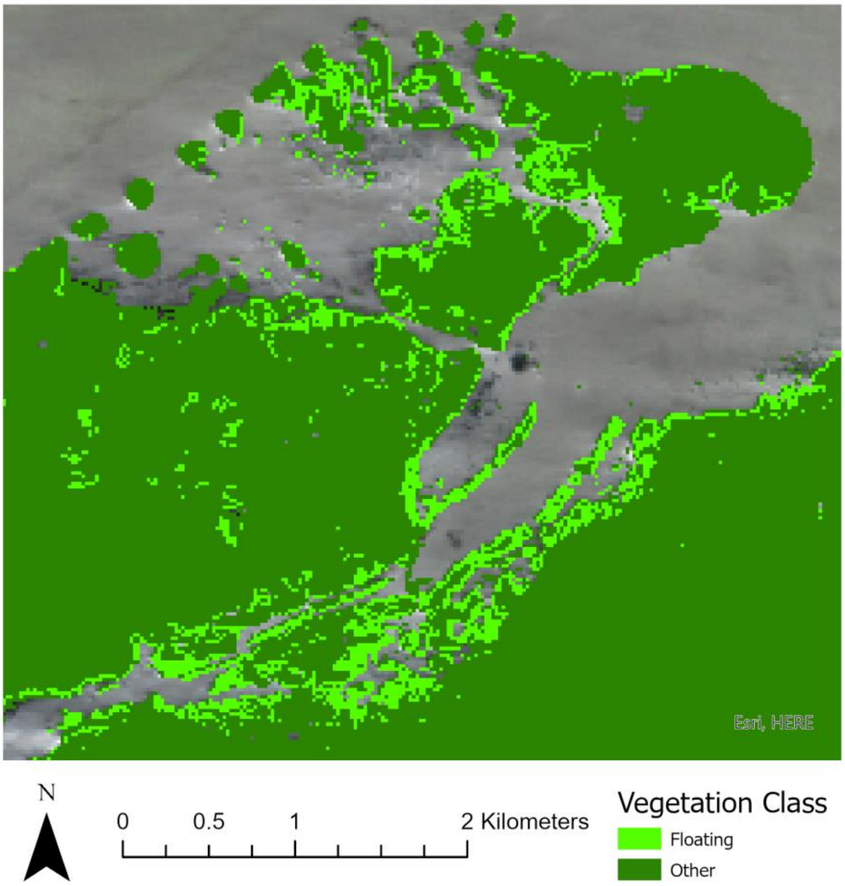

Figure 3: Floating weed map for region of Lake Okeechobee on 9th May 2019, distinguishing floating vegetation from other vegetation (e.g. emergent vegetation) using Sentinel 2.

Discussions with the customers highlighted that maps showing change in total vegetation cover would be of additional value. We used Sentinel-1 radar imagery, which is unaffected by cloud cover, to generate maps of vegetation change (Figure 4). Maps of total macrophyte cover generated from Sentinel 1 had a mean overall accuracy of 99% when validated against Sentinel-2 imagery.

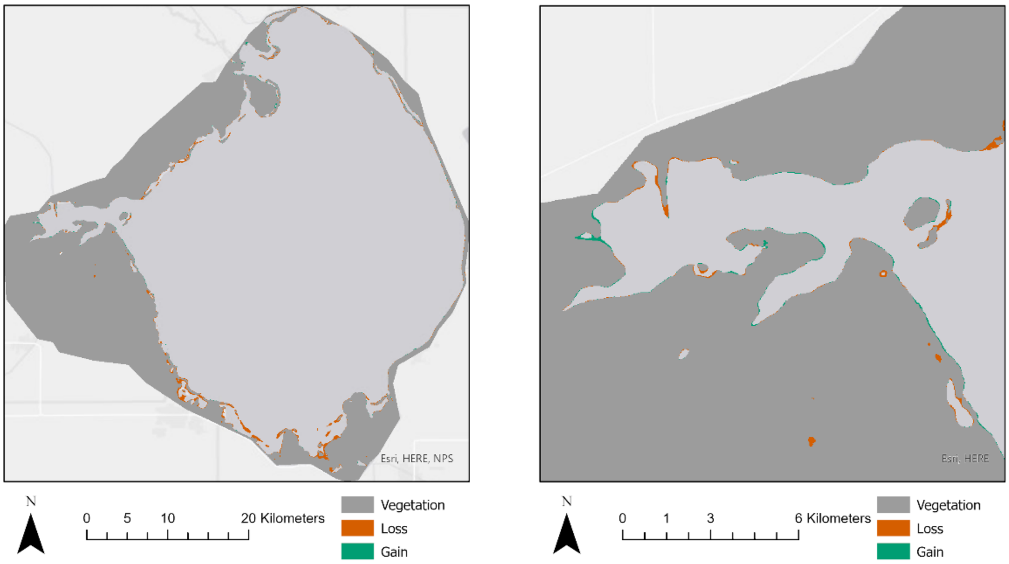

Figure 4: Change detection maps produced from Sentinel-1 SAR imagery. A & B show the difference in vegetation cover on Lake Okeechobee between 3rd and 15th May 2019. By highlighting vegetation loss and gain, we can identify free-floating vegetation with SAR imagery that is unaffected by cloud cover.

Other KPIs that were important to customers included spatial resolution, latency, and frequency of updates. Sentinel-1 and Sentinel-2 both deliver imagery at a spatial resolution (5 x 20m and 10 x 10m respectively) that meets the needs of most users. Some users require higher resolution data and so during the Demonstration Project we will investigate the spatial limitations of the data for resolving floating weeds and, if funding for commercial data is provided by the user, the potential of using PlanetScope imagery (3.7 m spatial resolution) as an add on service at additional cost for some users. Our investigations demonstrated that a latency of less than 48 hours is feasible. Sentinel-1 provides a revisit frequency of 12 days or better and Sentinel-2 imagery is available every 2 – 5 days. To overcome the problem of cloud cover in optical imagery our system will generate cloud-free composites from Sentinel-2 imagery. Our analysis showed that the mean length of time required for 90% cloud-free composite varied from 2 – 10 days depending on the region. This figure also varied seasonally but typically 90% coverage could be achieved within one to two weeks.

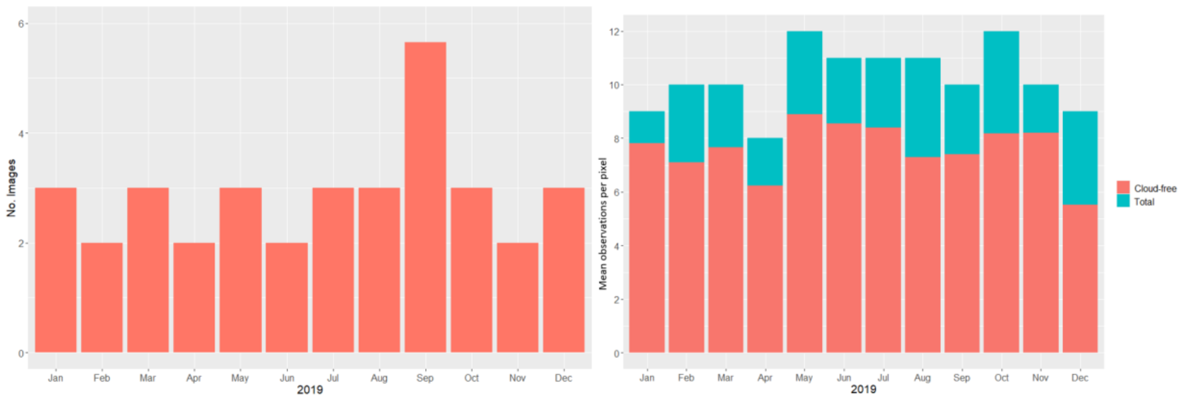

Figure 5: Average number of images per month (2017-2019) for Sentinel-1 (left) and Sentinel-2 (right) for Lake Okeechobee. For Sentinel-2 (right) the full bars show the total number of images per month, while the orange bars show the average number of cloud-free images per pixel on the lake during that month – giving an indication of the cloudiness of images.

A PoC web portal was developed which allowed visualisation and download of weed maps, timeseries and summary statistics. The final PoC including the proposed service offer, example maps and the mock-up of the services website was presented to customers to gather feedback. Users were impressed with both the floating weed maps and maps of total macrophyte cover and the web portal received praise for its ease-of-use and interpretability. Most respondents to the feedback survey believed the service would help them reduce costs and increase the efficiency of their monitoring activities. Some users required higher resolution imagery, and this is something that will be explored during the Demonstration Project. Respondents also suggested various minor improvements to the web portal that will be relatively simple to implement. Lastly, there was also an interest in maps that can distinguish different species of floating weed and this also something that will be investigated during the Demo Project.

6 Technical Feasibility and Commercial Viability of the envisaged Service

6.1 Technical Feasibility

The work conducted in this Feasibility Study has demonstrated that it is technologically feasible to deliver an EO-based floating weed monitoring system that meets users' needs. Informed by the KPIs identified through engagement with the customers, an end-to-end system/technical concept was devised, and system requirements were defined to enable the service offers and value propositions. Specifically, the system will deliver maps of total macrophyte cover from Sentinel-1 imagery with a revisit frequency of 12 days or better and floating weed maps from Sentinel-2 every 2 – 5 days. Maps will have a spatial resolution of 10 x 10 m which will be sufficient for most users.

The system architecture was refined (Figure 2) and the building blocks required to deliver the service have been described, including the required technologies and the developments needed for market readiness, including the EO space assets we plan to use, details of the processing chain and weed mapping algorithms, the processing platform, and the API and service website that will deliver datasets and visualisations to users. A processing chain for the EO imagery and weed mapping algorithms were implemented in Google Earth Engine's Java Script API. Proof-of-concept weed maps were generated and extensive validation work was carried out. Our analysis for the PoC demonstrated that Sentinel-1 and Sentinel-2 imagery are sufficient to produce maps with sufficient accuracy, latency, revisit frequency and spatial resolution to meet customer needs (see PoC for further details). A mock-up of the service web portal we produced, demonstrated potential layouts and features to customers including the ability to visualise and download maps, timeseries and summary statistics. Customers were impressed by the PoC maps and web portal and validated the preliminary design.

A review of various cloud computing services that could be used for the processing platform was conducted. The specifications of the processing platform required to run the processing change was characterised in terms of RAM, storage requirements etc. and it was determined that a basic set up will be sufficient however the exact set up required will be determined during the Demonstration Project when we will investigate and test various options including GEE, Open EO +EODC and an in house UKCEH server. Developments still required include investigating the use of PlanetScope imagery to provide high spatial resolution maps as an add on service at additional cost. The processing chain will also need to be adapted so that it can run on the GEE Python API as well as on other cloud platforms so that we have flexibility to switch between providers.

6.2 Commercial Viability

During the Feasibility Study, we worked closely with a range of key customers to understand the current and future demand for our proposed service. The project team also conducted a thorough assessment of costs related to service delivery. We examined viability for conservative and optimistic scenarios over a 5-year period. Our conservative estimates indicate a positive cash flow from year 2 onwards. Our optimistic (but realistic) scenario of customer uptake indicates a positive cash flow from year 1.

Whilst we acknowledge that more information on willingness to pay will become available as we move into the demonstration project, our analysis so far indicates that the proposed FWM service is commercially viable.

We note a lack of direct competitor at present. We also note interest in the service across the organisations with whom we have consulted. Hence, we believe this is, at present, a gap in the market, and furthermore one in which we can develop and expand our service.

A SWOT analysis identifies areas of opportunity, for example potential users in markets and sectors with whom we have not yet engaged. The analysis also identifies areas in which we are potentially weak, and we have taken steps to address these.

Overall, the commercial assessment carried out to-date indicates that the Floating Weed Manager service is viable. We expect the next steps in our assessment will provide more detail on likely revenue from customers not yet included in our forecasts.

7 Conclusions & Roadmap

The Feasibility Study has given us confidence that we have met the technical feasibility and commercial viability tests to deliver a commercial service that delivers a cost-effective service to customers to monitor and manage floating weeds. Engagement with a range of customers has refined our service offer and system design. Further investigations are still needed to finalise user and system requirements for a range of use cases: surveillance of small populations, monitoring to evaluate the effectiveness of weed control and species identification/flowering. Customers have started collecting relevant ground data for evaluating these issues in the Demonstration Project.

We have established very strong support from our Champion Customer USACE and other agencies in Florida monitoring weed distributions. There is also strong interest from customers in other regions, albeit with limited engagement in this Feasibility Study as we specifically focused our attention on a key market in the USA.

Following on from this Feasibility Study, the following roadmap of activities is planned for an 18 month Demonstration Project to take us to a position when we can launch a commercial, operational service:

Technical activities:

Months 1-3 (September 2021 - November 2021)

- Identify use case-studies and test case scenarios.
- Finalise user and system requirements.
- Rewrite the processing chain so that it can be tested and implemented in a range of processing platforms.
- Train and validate the weed mapping algorithm for more geographical regions.
- Determine what set up is required for the cloud processing platform.

Months 4-6 (December 2021 – February 2022)

- Test different cloud processing options.
- Investigate the possibility of an in house UKCEH server.
- Investigate potential for additional products including species level maps and plant health.

Months 7-8 (March 2022 – April 2022)

- Update the processing to automatically produce a map each time new imagery becomes available.
- Finalise the system architecture.

Months 9-10 (May 2022 – June 2022)

- Develop the code for the final processing chain.
- Set up an API for delivering data directly to customers and to the web portal.
- Produce fully functioning web portal that takes data delivered by the API.
- Document and test the final system.

Months 11-16 (July 2022 – Dec 2022)

- Pilot system evaluation

Customer Engagement and Commercialisation Activities

Months 1-3 (September 2021 - November 2021)

- Determining user requirements in more regions
- Gathering feedback on pricing structures and mechanisms with potential customers

Months 4-6 (December 2021 – February 2022)

- Finalising user requirements in new regions (South Africa, Australia, New Zealand)
- Evaluating pricing structures and mechanisms with potential customers

Months 7-9 (March 2022 – June 2022)

- Finalise commercial partnership operations in light of finalised service architecture and IP.

Months 10-18 (September 2021 – February 2023)

- Finalising pricing structures and licencing mechanisms with customers
- Developing marketing brochure and digital marketing materials
- Secure at least two more customers/markets

8 References

CABI, 2019. Eichhornia crassipes (water hyacinth) datasheet. Accessed on 25th April 2021 at https://www.cabi.org/isc/datasheet/20544

Cuthbert R.N., Pattison Z., Taylor N.G., et al., 2021. Global economic costs of aquatic invasive alien species. Science of The Total Environment, 775, 145238. Accessed on 25th April 2021 at https://www.sciencedirect.com/science/article/pii/S0048969721003041

Theuria M., 2013. Water hyacinth—can its aggressive invasion be controlled? United Nations Environment Programme (UNEP) Global Environmental Alert Service Report, April 2013. Accessed on 25th April 2021 at https://na.unep.net/geas/getuneppagewitharticleidscript.php?article_id=98