EMFF Operational Programme 2014-2020

Blue Growth & Marine Spatial Planning Scheme

# Development of Methodologies for Assessment of Ireland's Seaweed

## Project completion report


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Foras na Mara
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## Background

The harvesting of wild seaweed, and its use as a food, animal feed and soil enhancer has been ongoing for centuries in Ireland, and is an important part of the social, economic and cultural fabric of many coastal communities. The increasing demand for seaweed as a raw material in the production of traditional products, as well as emerging areas (beauty products, biochemical applications and pharmaceuticals), points to an area of great potential economic value. However, seaweed is of critical importance to the wider marine ecosystem so the challenge for the sector's future is to ensure this valuable resource is, first and foremost, protected, while exploring emerging opportunities.

The last national-wide survey to assess seaweed resources of Ireland was performed in 1998 ((Hession et al., 1998). Since then global production of algae has grown four-fold, reaching over 32 million tons, with the value exceeding €10B. Ireland is one of the largest producers of seaweed products in Europe, which accounts for 1% of the global production, 90% of which being concentrated in Asia (Monagail, M.M, 2020). In recent years there has been a global growing interest in seaweed resources, largely driven by research into biofuel technologies, pharmaceutical, food and cosmetic industries. In addition to being an eco-fuel, algae can also represent a substantial sink for CO2 generated by anthropogenic activities and help achieve carbon reduction targets set out in the Green Deal of the EU. In Ireland, commercial interest in seaweed resources has been rising, with international industry players seeking large scale regional licenses for resource harvesting. In parallel, local harvesters are extracting seaweed in an ad-hoc manner, with no regional or standardised protocol, methodology, or pre-harvest biomass assessment being undertaken (Monagail, M.M, 2020).

Overall, the value of the Irish seaweed industry to the Irish economy has been steadily growing over the past decade. In 2011, the industry was worth ~€18 million (Morrissey et al., 2011). In 2018 seaweed worth €37 million (77,000 tonnes) was exported from Ireland (BIM, 2020), while the most recent socio-economic report commissioned by the Marine Institute estimate the current value of the industry to between €80-90 million.

From a social perspective, seaweed harvesting provides valuable rural jobs, but the effort and resource is undervalued and being underutilised due to lack of standardised resource management, no national guidance or requirements to adhere to best practice sustainable harvesting approaches, and baseline resource data.

In order to document the overall Socio-Economic status of Seaweed Harvesting in Ireland, in 2021 the Marine Institute commissioned a study to provide a baseline socio-economic information regarding seaweed harvesting activity and product usage in Ireland today. This study provides important background information for Ireland's National Marine Planning Framework (NMPF) and will inform the development of national policy for the sector. One of the key messages in this report is that continued growth in an industry that provides high value employment and a positive economic contribution to coastal communities in rural Ireland must be balanced against ensuring that the level of seaweed harvesting is sustainable and is capable of continuing replenishment and availability of this natural resource for future generations.

The overarching concerns are that increased biomass harvesting demands have the potential to damage marine habitats, ocean biodiversity and ocean health. It is clear that a data driven approach in which ocean ecosystems and seaweed biomass (wild growth, harvested and farmed) are monitored would provide means by which to accurately protect the oceans and support the scaling of the seaweed industry dimension of the Blue Economy.

## Project rational

One fundamental element required in order to guarantee long term sustainability of the sector lies on our ability to accurately monitor seaweed resource distribution and abundance.

Until recently, seaweed resource assessment has been painstakingly undertaken by on the ground ecologists, physically inspecting seaweed distribution and biomass during intermittent transects of the intertidal zone. Scale up estimations of resource are then based on visual studies on the water e.g. by canoe, or walking the coastline, or sometimes by larger operators based on conventional RGB camera data (red, green, blue) (Monagail, M.M, 2020).

Some initial research funded by the Marine Institute (Rossiter et al., 2000) demonstrated that short range airborne deployed multispectral and hyperspectral camera systems (i.e. cameras with multiple frequencies) can acquire data at a resolution accurate enough, and with spectral (colour frequency) information detailed enough to accurately map distribution and extent of certain commercially valuable species within the flight range of the vehicle.

Scaling up this approach to address regional resource baseline mapping was at the core of the EMFF funded initiative in order to further develop 3rd party technical expertise in this niche sector.

In 2019 a project proposal was submitted as part of the EMFF Operational Programme 2019-2020 Blue Growth and Marine Spatial Planning Scheme seeking a total funding of 250.000 Euro toward the development of Methodologies for Assessment of Ireland's Seaweed Resource. Proposal details are provided in Appendix 1.

An initial market analysis was conducted in 2019 to assess the availability of commercial services capable to deliver various aspects of the project such as the delivery of hyper and multispectral surveys in coastal and intertidal environment and capable to develop the required data analysis and mapping solutions. The outcome of this analysis indicated an absence of commercial providers of aerial, drone or remote sensing services capable to deliver intertidal or subtidal seaweed resource assessment. Since the ultimate goal of the project was to create a technology focussed methodology and data analytics flow to derive seaweed distribution, which when augmented by groundtruthing, would enable regional scale species specific intertidal seaweed biomass studies, one of the primary task initiated as part of the project was to stimulate the implementation of these new methodologies within SME's and generate commercial services. This lead to further conversations with Enterprise Ireland and eventually decision was taken to use the majority of the funds allocated to co-fund a Small Business Innovation Research (SBIR) initiative. The SBIR funding mechanism falls under pre-commercial procurement and it enables public bodies to fund research and stimulate innovation, when goods or services are not available in the marketplace. The ultimate aim of this process was to incentivise SME's to develop new seaweed mapping services with potential to benefit SME's focused on latest remote sensing survey technologies, while also insuring long term sustainability of the developed solution and also develop services that can be utilised by both Government and private sector to:

- define baseline resource assessment nationally, which is essential to support permitting decisions to seaweed companies, and to ensure sustainable and effective harvesting approaches are developed and implemented.
- create significantly more efficient monitoring approaches for future resource management.
- Expand Ireland capacity in multiple coastal resource assessment and risk management applications.

This initiative was co-funded by EI (150.000€) and by 150.000€ provided as part of this EMFF project fund.

In parallel and in order to support this EMFF project a hyperspectral camera system and associated drone deployment unit were procured via Tender process (see ITT20-044).

Hyperspectral cameras record very high resolution imagery within a wide bandwidth of frequencies, enabling complex data analytics and the identification of subtle changes in colour, and in turn habitat and/or species. Data derived from these sensors have vast applications in earth, agricultural, marine, geological and environmental science. The intent was to provide this state of the art hyperspectral camera infrastructure to the SBIR funded companies and academic partners in order to stimulate the use of this technology within the scope of intertidal sea weed mapping.

This report aims to describe key measurable outputs that were achieved between 2020 and 2022 under this funding initiative.

## EMFF proposal measurable target outputs

The measurable target outputs in the initial EMFF proposal are listed below. The following sections will provide a description of progress made under each sub section and, where appropriate, future recommendations.

1) A scalable survey methodology for seaweed resource assessment.
2) Completed hyperspectral and acoustic studies of seaweed resource;
3) Completed multi-site biological sampling and identification of seaweed resource;
4) Broadscale site specific seaweed species & coverage distribution;
5) Spatial data products and maps demonstrating the seaweed resource in Ireland.

## A scalable survey methodology for seaweed resource assessment

Remote Sensing technologies have been used for many years to spatially map and quantify many resources around the globe but its application to seaweed monitoring is still in its infancy in particular in complex settings such as the coast of Ireland where many environmental challenges are present.

Remote sensing involves the observation of a target area by a device from a distance and covers a wide variety of technologies, platforms and sensors. Information can be obtained from satellites via multispectral or hyperspectral sensors, from aircraft or drones via aerial imagery/LiDAR, and from ships using SONAR and underwater imagery (Bennion et al., 2019).

Each technique has its own limitations and results can be affected by weather, water turbidity, water depth, changing tides, sun glare and so on. Satellite imagery can provide snapshots of larger areas which are vital when large scale baseline studies are required. Data provided by National agencies such as US National Oceanic & Atmospheric Administration and European Space Agency are also mostly free and with a very high temporal resolution (daily or weekly passes over the same area) which is ideal for regular monitoring while also reducing costs associated with data collection.

Despite this, at the moment, satellite data do lack the spectral and spatial resolution that can be achieved using aerial imagery collected from aircrafts or drones even tough recent commercial satellite data providers such as WorldView, Planet Labs or others have started to bridge the gap.

When choosing any given mapping technique, there is a trade-off between spatial coverage, resolution and labour intensity (either field or desk based). The answer to a standardized remote sensing technique to quantify seaweed resources may therefore lie in a combination of multiple sensors and techniques. Until standardized monitoring procedures are available to industry and regulators, the ability to accurately map and monitor seaweed resources and accurately inform management and harvesters will remain poor in particular where monitoring needs to be done on individual species.

Decision trees like the one published below (fig.1, Bennion et al., 2019) can help the selection of appropriate remote sensing tools for mapping submerged and intertidal macroalgae.

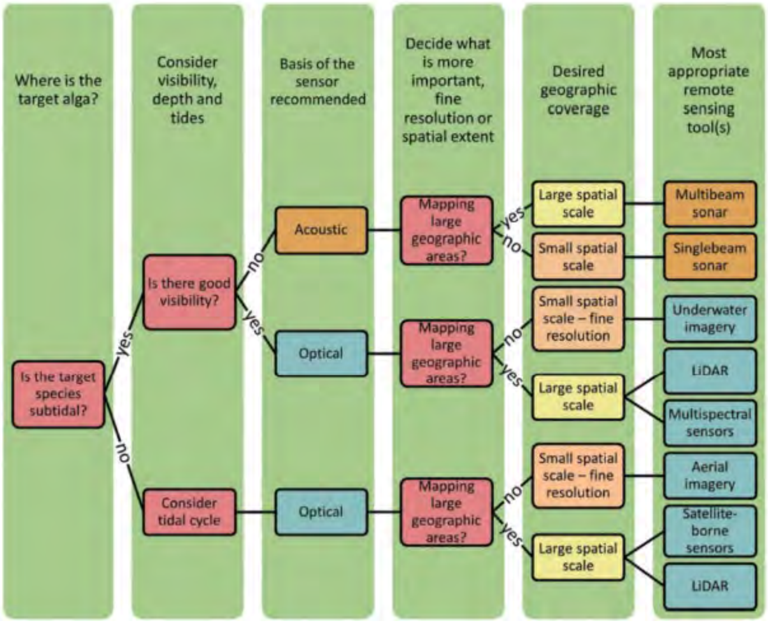


*Figure 1 decision tree used to aid the selection of appropriate remote sensing tools for mapping submerged and intertidal macroalgae.*

<u>It is within this context that the SBIR initiative was developed.</u>

As part of the SBIR initiative, three independent consortia were funded to assess and develop the best methodologies to carry out regional scale mapping of intertidal seaweed at species level in Ireland.

The first phase of the SBIR initiative funded the consortia for 4 months to develop initial project demonstrators and plans for the development of a fully scalable solution. This initial phase was completed in Dec 2021 and two consortia (AAT and Fathom) moved to the second stage of development which took place in 2022.

The following section will provide details on the solution developed by each of the consortia

### *AAT proposed solution*

Aerial Agri Tech (AAT), consortia included AAT, Copernicus, Terra and Aran Island seaweed.

AAT already operated in the agricultural and forestry sector using remote sensing to monitor crops/weed, and they had confidence that this approach could be adapted to the intertidal environment for seaweed assessment. Their technical solution, data sharing plan, business model and service to customer solution reflect their extensive knowledge of the methodologies and their commercial capabilities

AAT used three key inputs as a means of testing the suitability of remote sensing outputs to record and monitor the presence of seaweed within the intertidal zone along the Irish coast (fig. 2).

Satellite and aerial fixed wing drone-derived multispectral imagery were used to classify seaweed at three scales; national, regional and local using coarse to very high resolution imagery. A series of algorithms were created per image acquisition category in order to identify the most efficient and accurate means of automated detection of seaweed. Classification objectives were broken down into three categories relating the sensor and image resolution as follows:

- Satellite (10-20 m), county scale: identify the presence of seaweed along the coast using freely available Sentinel 2 satellite data. This lead to the development on a National Atlas of Seaweed presence/absence.

- Aerial/very high resolution satellite imagery (0.5-3 m), regional scale: identify algal macro classes – red, brown and green.
- Drone (1.5-5 cm), local scale, identify classes and species, e.g. Fucus spp., Ulva spp., ascophyllum nodosum etc.

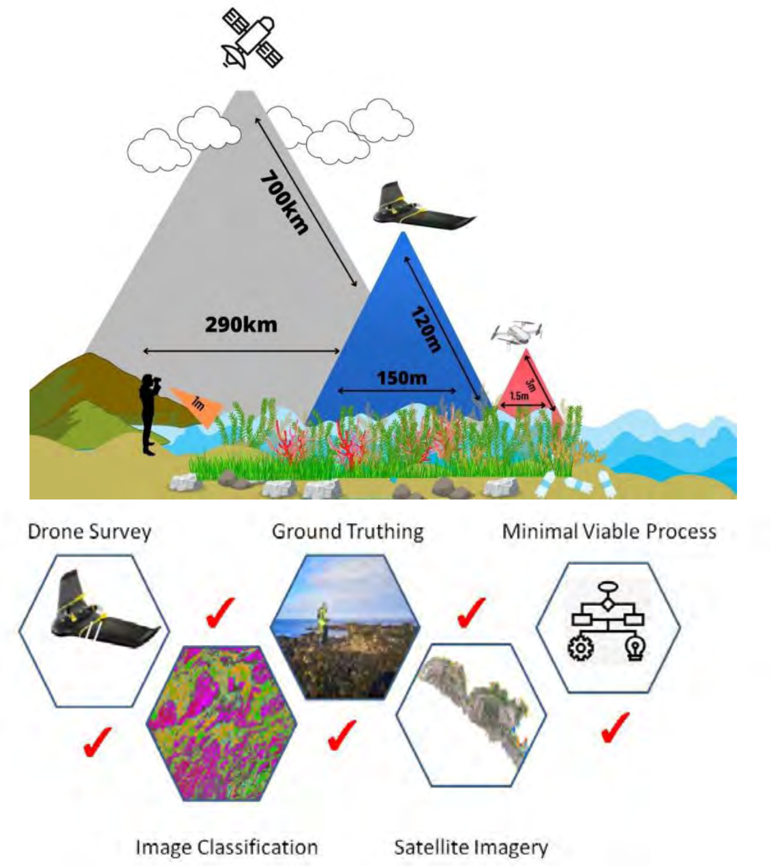


*Figure 2 Multiple tiers approach adopted by AAT.*

Between 2020 and 2021 extensive field work was carried out by AAT on multiple sites to fine tune methodologies, select the correct sensors, drones and test the limit of satellite and drone multispectral technologies to detect individual seaweed species.

In synthesis, AAT demonstrated that free satellite data (Sentinel-2) can be used for large-scale mapping and detection of seaweed aggregates presence which can then be used to fine tune regional or local scale detailed surveys. Additionally, it was demonstrated that fixed wing drones combined with the correct multispectral sensor and field survey techniques have the potential to survey large areas of the coastline in relatively short amount of time. AAT also demonstrated that composite RGB and multispectral sensors, while limited in their spectral resolution when compared vs hyperspectral equivalent, can separate macro classes of seaweed and in specific circumstances, can also distinguish between certain species. For example it was possible to separate *A.nodosum* from *Fucus spp*. with the accuracy of 75-80%, it was possible to map presence of *H.elongata* and also detect the extent of submerged vegetation. A comprehensive report discussing all the methodologies, sensors and algorithms used for data collection, analysis and interpretation, together limitations, survey considerations and guidelines is provided in appendix 2.

*Fathom proposed solution*

Fathom Technologies consortia included Fathom, Arramara Teo and two groups in NUIG.

Fathom approach to intertidal seaweed mapping focused primarily on the exploitation of commercial satellite EO data coupled with machine learning models and cloud computing power provided by Amazon Web Services (AMS).

Recognising the complexity (technical and legal) of flying drones/aircrafts, Fathom vision of the project was to develop a platform where users can feed satellite EO data as an input, and the platform would output seaweed mapped statistics. Ascophyllum nodosum, the most commercially important wild seaweed in Ireland was the primary focus of this initial development, Once fully developed, the application can benefit both policy makers and seaweed harvesting companies with the creation of near real time seaweed maps and abundance statistics for the area of choice.

At the heart of this solution are EO satellite data since they can be relatively cheap to acquire, are available periodically without the need of any operator or field work, and have been shown to be highly effective in accurately categorise intertidal substrates and seaweed species into specific classes in Irish waters (Bermejo et al., 2020).

Commercial Earth observation data sets from Planet Labs (3-5 m resolution available daily) and WorldView (<0.5 m resolution available daily), both collected during intertidal times, were tested in the context of the mapping of ascophyllum nodosum, resource. Additional EO data were also derived from Sentinel-1 Synthetic-Aperture Radar from the ESA which provided radar backscatter data needed to derive surface roughness. Images were correlated with extensive field data (>700 sampled location) which were independently used for model creation and validation.

The EO data and the field data were used to develop a complex model with ability to predict the spatial extent and biomass of seaweed. The entire model was developed using Google's TensorFlow, a free and open-source application which takes advantage of machine learning and neural networks algorithms.

The model was assessed in two steps, one for testing and another for the validation site. The assessment did indicate model error margin of +/-6 Kg/m$^2$ for 80% of data. Fig. 3 shows the comparison results from the model to the data collected on the field. The number on the horizontal axis corresponds to the cluster number and the vertical axis shows the magnitude of biomass in Kg/m2). The green curve shows the field value whereas the blue shows the results from the model. The red curve indicates the difference between the model and field results. From a commercial perspective, it is considered a medium range of success which could be further improved using higher resolution detailed surveys (drone images) and ingestion of more data into the model. This level of accuracy, which can be obtained just using EO satellite data could for example be used by seaweed harvesters to define areas of high (>12Kg/m$^2$), medium (8-12Kg/m$^2$) and low (<8 Kg/m$^2$) biomass which they can target for harvesting.

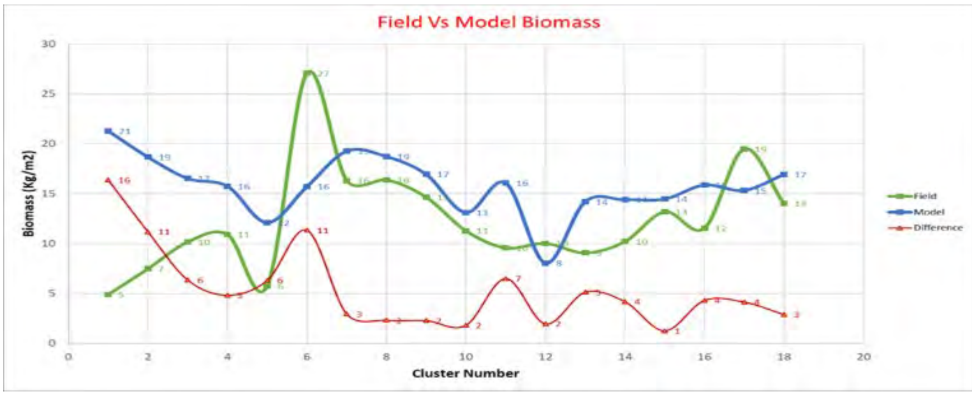


*Figure 3 Comparison of the results from the model to the ones from the field survey.*

Once the approach was proved to be reasonably accurate, the second phase of development consisted in the creation of a Website and Dashboards where users can upload EO data and extract key metrics from the project, such as biomass levels, heat maps representing the biomass prediction of the seaweed in the region they have selected and then download a report that displays the information in a format that can be shared.

The project website is available here: [https://algasat.com](https://algasat.com)

The landing page (fig. 4) is used to provide information on how the service works and how the project came to be. From here, users will be able to login to the platform and upload sample files and see the biomass calculator working. This required the development of both an Admin APP and Customer APP. The Algasat Admin app is an internal application used to manage users of the Algasat platform. The Algasat customer app is instead a web application that allows customers to provide satellite images, which will be transformed and made ready for processing, and receive predicted biomass information from the image.

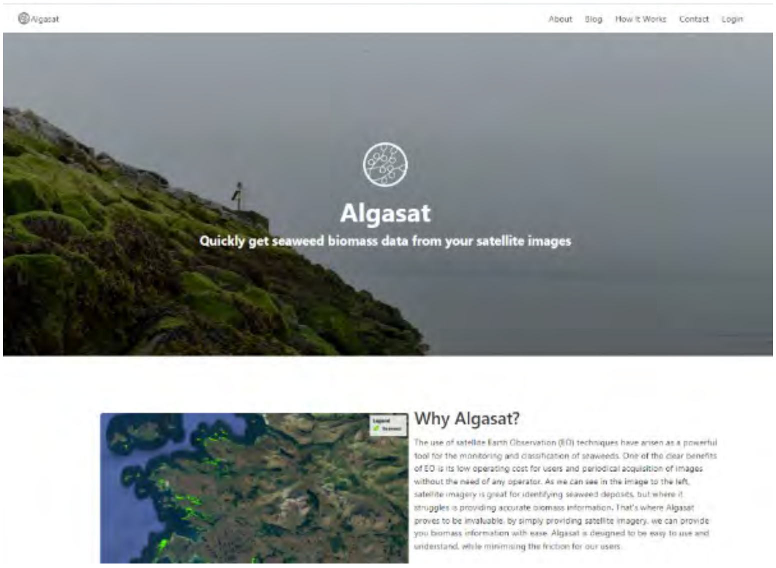


*Figure 4 Landing page of the Algasat project.*

### *TechWorks Marine / GeoAerospace proposed solution*

TechWorks Marine consortia included TechWorks Marine, GeoAerospace and NUIG

Techworks Marine consortia was awarded the first phase of SBIR and they completed an initial methodology review and some preliminary field work during Q4-2020. While this consortium didn't move into phase two of development, mostly due to one of the key consortia members leaving the project, the proposed solution was quite well developed and similar to the one proposed by AAT.

In synthesis, the proposal was to develop a novel seaweed mapping platform incorporating multi-thematic data acquisition, data-fusion, highly automated ML workflows as well as geospatial analysis & visualisation tools.

The approach consisted in combining Optical data (RGB, Multispectral as well as hyperspectral) and LiDAR (point-cloud) using light aircraft and drones and then combine these datasets to produced orthomosaics, digital surface models, and point cloud. In parallel the plan was to use multispectral and hyperspectral data to build high-quality training datasets (seaweed spectral libraries) to be used for Machine Learning workflows. Additionally, the plan was to use freely available Copernicus Sentinel 2 data (10m resolution) in combination with unsupervised and supervised methods to classify coastal areas into permanent water, mudflat, sandy/gravel beach, rocky shoreline, seaweed, and shallow water. While Sentinel 2 data doesn't have enough resolution and spectral band to map individual seaweed species, its ability to classify presence/absence of seaweed on complex coastlines can support more targeted aircraft survey and drone data acquisition campaigns. Finally, the proposal included the development of a client based web portal for storage and delivery of survey data and reports.

While the consortia didn't manage to fully develop the project, initial results achieved in the first few months (Q4-2020) are presented below to showcase the potential of remote sensing methodologies in classifying seaweed species using multispectral data.

During this short period of time, two areas in Connemara (Co Galway) were selected to trial various methodologies. Sentinel-2 data for the area of interest was examined to verify the use of large scale freely available satellite data to provide indicators of seaweed biomass using a common terrestrial vegetation index known as the normalized difference vegetation index (NDVI). This confirmed that space borne remote sensing can provide a reliable identifying and mapping seaweed areal extent in intertidal zones (similar to the methodology used by AAT). Onsite, RGB and multispectral sensor data were collected using drones. These data were used to build high quality training datasets (seaweed spectral libraries) for machine learning workflows. The outputs included orthomosaics, Digital Surface Models, Point Clouds, and high-quality labelled training datasets. In addition, machine learning workflows were developed and tested (e.g., sematic segmentation) for automatically classifying and quantifying seaweed species. A three-step approach was developed for the purposes of demonstrating this novel approach:

Step 1: Segmentation and data extraction

- Using the Micasense Altum and DJI P4 multispectral imagery, a mean shift Segmentation algorithm was employed. For each segment generated, the mean value per multispectral band along and mean elevation was extracted. Elevation appears to be a significant indicator of seaweed species.

Step 2: Classification of Seaweed/ Non-Seaweed

- Manual photo-interpretation of imagery was undertaken to manually label segments as either above-water seaweed or not seaweed. A Random Forests model was trained using the DJI P4 multispectral Red and NIR bands and elevation, obtaining a 99% accuracy in k-folds cross-validation.

Step 3: Classification of Seaweed

- Ground truthing data samples were separated into training and validation datasets. For each seaweed class, at least five validation points were selected that were spatially separated from the remaining sample points for that class. Four Machine Learning techniques were explored to classify the data, with the best results obtained using Random Forests with 71% accuracy using the in-training data and 67% accuracy in the validation data.

Step 4: Visualisation

- The various data outputs were uploaded to the GeoAerospace cloud platform for visualisation purposes. An example is shown below (fig. 5).

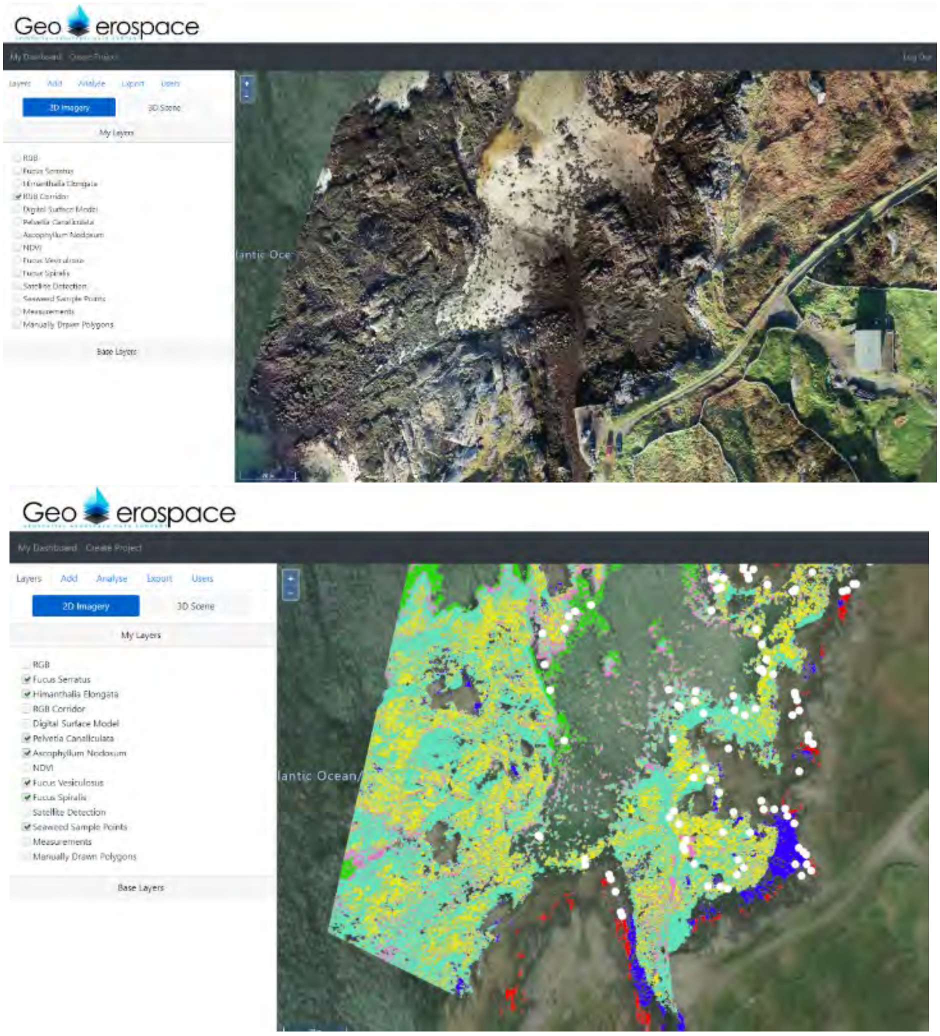


*Figure 5 Classified seaweed resources uploaded to the GeoAerospace cloud platform.*

## Completed hyperspectral and acoustic studies of seaweed resource

### Acoustic studies of seaweed resources

Sub tidal kelps and other seagrasses forests are one of the most productive habitats found within the coastal zone (Steneck et al., 2002) With a general lack of information on the impacts of anthropogenic pressures (Ierodiaconcou et al., 2007), detailed baseline ecological data must be collected to allow for informed, sustainable decision on how to manage these resources and the anthropogenic activities associated with them (Jordan et al., 2005).

Survey methods for kelp and other subtidal species, including seagrass and freshwater macrophytes, can be broadly assigned to three different categories.

Field survey methodologies will typically involve the direct sampling and measurement of subtidal species (Abukawa et al., 2013) such as through SCUBA or video transects using either drop cameras or guided ROV's. These methods can deliver the highest level of detailed biological data but tend to be costly, time-consuming (Hasan et al., 2011), depth limited and may not accurately capture the complexity and spatially heterogeneity of habitats (Brown & Collier, 2008).

Optical remote sensing technologies from either satellites or airplanes have the potential to cover large areas very efficiently but they tend to be limited by light penetration in the water and often unsuitable for assessing subtidal habitats in turbid environments (Brown & Blondel, 2009; Bajjouk et al., 2015). Although several studies have successfully used satellites data to accurately map the distribution of subtidal kelp beds, they have still been limited to relatively shallow depths of < 10 m (Casal et al., 2011; St-Pierre & Gagnon, 2020). This means that a full distribution map cannot be achieved for kelps which occur over broad depth ranges (McGonigle et al., 2011).

Acoustic remote sensing technologies are not constrained by the optical properties of water (Kruss et al., 2017) and poor visibility. Modern sonars such as hydrographic or fisheries echo sounders can record acoustic returns, not just from the seabed, but also from the water column, enabling the detection of fish (Cushing, 1952; Weber et al., 2009) and submerged aquatic vegetation (SAV). Marine vegetation such as kelp can be observed as a weaker acoustic signal above the seabed, which is caused by the density contrast between SAV and the surrounding water (Warren & Peterson, 2007; Lefebvre et al., 2009) and also the diffuse reflection of acoustic energy. This unique acoustic signature (weaker than the seabed, but stronger than the water column) can be isolated and theoretically used to determine the presence and height of SAV (Minami et al., 2010). Height and distribution maps have been successfully created for *Laminaria spp*., in Japan, using SBES (Minami et al., 2010) and in the USA, using MBES (McGonigle et al., 2011). Seagrass canopy height and abundance has also been successfully mapped in the UK with SBES (Lefebvre et al., 2009) as well as with MBES in Japan (Komatsu et al., 2003). In some cases, acoustic signatures have been used to discriminate between broad taxonomic groups, such as macroalgae and seagrass (Riegl et al., 2005). Various methodologies for multibeam water column data extraction have also been developed (Schimel A.C.G et al., 2020; Porskamp P. et al., 2022). All these studies demonstrate how the choice of acoustic frequency used can influence the sensors ability to detect SAV. Previous studies mapping SAV used frequencies in the range of 200 kHz (Minami et al., 2010; Kruss et al., 2017) to 500 kHz (Komatsu et al., 2003; McGonigle et al., 2011) as they are better at detection features within the water column.

Acoustic studies of seaweed resources were completed by the Marine Institute as part of an ongoing research on underwater seaweed mapping (Rossiter T. et al., 2019) in order to explore the potential to use conventional multibeam echo sounders (MBES) mapping sonars to map kelp resources. Primary questions that had to be addressed included the following

- Can MBES and water column data analysis be used to identify the presence of subtidal kelp beds?
- Is it possible to derive accurate distribution and canopy height values using MBES data?
- What recommendations can be made about the suitable of MBES and water column data in the development of a wider-scale resource assessment methodology?

Investigation was performed using different type of industry standard instruments operated at different frequencies.

In summary, the conclusion of this investigation indicated that:

- Multibeam data and in particular the water column component, can effectively identify the presence of macroalgae, deriving both canopy height and bed distribution data.
- Most shallow water multibeam frequencies (200-400khz) can identify the presence of kelp and produce distribution and canopy height maps.
- Multibeam echosounders are primarily designed to precisely map the seabed. These devises do suffer from side lobe interferences on their outer swath portion. These are particularly visible in the water column part of the data and can be an issue when user need to analyse water column, attempting to extract SAV informations. This problem has been previously described by McGonigle et al. (2011) and Kruss et al. (2017) who both described how sidelobe interference made it difficult to confidently identify kelp beyond the central beams of the MBES data as the interference was sometimes greater than the acoustic response of macroalgae. The presence of side lobe also makes automatic feature extraction and quantification challenging.
- Multibeam water column datasets tend to be considerably large, in the order of 10x standard multibeam bathymetry datasets.
- Considering both the data analysis challenges posed by side lobe artefacts and also the limitations imposed by data compression, storage and processing, using underwater acoustics for large scale surveys of subtidal seaweed may be impractical.
- Instead, using a multi-layer mapping approach, similar to that used by Bajjouk et al. (2015) may be a more effective and economical way to monitor these types of habitats in particular in contexts like Ireland where nearly all the coastline is mapped already to the highest detail thanks to the INFOMAR seabed mapping initiative. In this case, INFOMAR data can be used to derive very detailed morphology and sediment distribution maps where accurate hard substrates are delineated. This can then be combined with habitat suitability models of presence–absence of seagrass and kelp which takes into consideration the substrate layer plus many other environmental factors needed for these species to be present. Models can then be validated using either satellite remote sensing (where water classify allows) and vessel mounted acoustic remote sensing. Further species validation can then also be obtained using conventional field techniques such as SCUBA or underwater cameras. This can also be conducted in a stratified way, with a predetermined set of sampling stations (Bajjouk et al., 2015) based on the acoustic data results.

Hyperspectral studies of seaweed resources

One of the main limitation of remote sensing for habitat mapping and species identification has been, until now, the ratio of pixel size to spectral bandwidth of current sensors, which is too big to either get a sufficient spatial resolution or sufficient spectral discrimination of species.

Currently, multispectral surveys are still the default methodology used in most remote sensing applications.

Previous research conducted by the Marine Institute and the work carried out by the SBIR consortia demonstrated that aircraft or drone deployed multispectral sensors can provide an effective macro algal resource assessment tool when used in environments with low species diversity and homogenous cover of canopy-forming species (Rossiter T. et all., 2020)

However, the spectral resolution of these sensors, with few and wide bands, only allow to differentiate algae from other coverages, as sand or rock or, at most, separate green from red or brown algae; no further taxonomic classification is possible.

Seaweed communities can be spatially and spectrally complex, with species occurring in mixtures over fine scales, requiring high spatial and spectral resolutions to accurately identify the species present (Oppelt et al., 2012). Luckily, technological advances are overcoming these limitations. Drone-borne camera are now capable of providing centimetre resolution images, representing two orders of magnitude improvement over satellite-borne imaging sensors. Furthermore, hyperspectral sensors are being developed with over 200 spectral bands in the visible-infrared (VISNIR) spectral range (each narrower than 3 nm), giving much more spectral resolution than multispectral sensors, i.e., resolving finer spectral features. The parallel advance of technology miniaturization allows hyperspectral sensors to be transported by drones, enabling challenging goals in remote sensing such as species identification, particularly for those species with similar spectral properties such as intertidal seaweed communities, to be achieved.

While hyperspectral remote sensing technology has clear advantages, it also brings many new challenges including data collection and calibration, large and complex datasets which require new classification and feature extraction methodologies and the need to have dedicated reflectance spectra for each of the individual species to be mapped. Identification of reflectance spectra for each environmental parameter or seaweed specie is particularly important since the spectral radiance of these can change based on many factors and published spectral libraries are relatively scare in particular in an Irish context.

To facilitate further research and possible commercial development of hyperspectral remote sensing within intertidal seaweed mapping context, part of the EMFF funding was utilised to procure a hyperspectral camera system and associated drone deployment unit via Tender process was procured (see ITT20-044).

While the intent was to provide this state of the art hyperspectral camera infrastructure to the SBIR funded companies and academic partners in order to stimulate the use of this technology, this was not possible due to various factors including

- COVID. The SBIR initiative was funded and delivered during a World pandemic. This affected several aspects of the project such as field work, ability to test equipment and develop training programmes.
- Timeline. By the time the hyperspectral system was delivered (early 2021) the two SBIR awarded consortia had already established their work plans which was mostly focused on multispectral data. The only company with previous experience with deployment hyperspectral sensors (GeoAerospace) had left the SBIR initiative at this stage and the remaining consortia had no in-house technical capabilities to implement this technology within the time frame allowed by the SBIR initiative, without compromising on their already planned key deliverables.
- Drone flight licencing. While AAT consortia had extensive experience with deployment of light fixed wing drones (with multispectral cameras), they had limited knowledge on how to operate large, heavy payload multi rotor drones.

While it was not possible to collect hyperspectral data and stimulate further research on this topic within the timeframe of the SBIR project and the EMFF funding, the hyperspectral camera and associated drone system is now part of the Marine Institute asset and during 2022 this has enabled the following:

- A Cullen fellowship PhD scholarship focused on Marine and Coastal Environmental monitoring using drone and aerial Hyperspectral Imaging sensor was launched in mid-2022. The awarded University will take full advantage of this infrastructure and conduct further research on the use of hyperspectral remote sensing as a tool to monitor both coastal seaweed and other marine environmental factors.
- A formal infrastructure sharing agreement was reached between the Marine Institute and the Dept. of Electronic & Computer Engineering at University of Limerick (Gerard Dooly). The group under Dr. Dooly already operate a number of similar drones and autonomous vehicles and have all the required engineering and legal licences that enable them to mobilise and fly this infrastructure. The agreement is that UL will utilise the camera to support some of their marine monitoring projects (seabird monitoring, infrastructure and wind farm inspections) and provide technical and pilotage support to other universities and Marine Institute projects when needed.

## Completed multi-site biological sampling and identification of seaweed resource

During the development of the SBIR initiative, the three consortia deployed their technology solutions on multiple sites and completed extensive biological sampling to validate the remote sensing data. The following list summarise the sites that have been investigated.

### AAT

Several sites were selected, some stretching across 30-50 km along the Irish coast.

Sites included

- Inis Mór, The Aran Islands,
- Quilty, Co. Clare
- Clew Bay, Co. Mayo
- Beara Peninsula, Kerry-Cork, Co. Waterford
- Inishowen peninsula, Co. Donegal,

The sites were selected in order to encapsulate diverse and complex regions from areas rich in mixed species, to more uniform sites like certain areas of Bantry Bay with one dominant specie. Extract of the AAT report showing the seaweed mapping work carried out in Inis Mór site (Aran Islands) is reported here as a demonstrator of the work carried out. Further details of the surveys and associated biological sampling is included in the AAT report (appendix 2).

**Inis Mór, The Aran Islands,**

A total of 15 surveys were conducted, capturing data at different tidal phases, low, mid and high, allowing to compare submerged vs exposed conditions. Initial analysis of satellite data was used to narrow down areas most relevant for presence of seaweed. Fig. 6 shows satellite data vegetation index analysis of Inis Mór and, to the right, the selected area for field work (fig. 6).

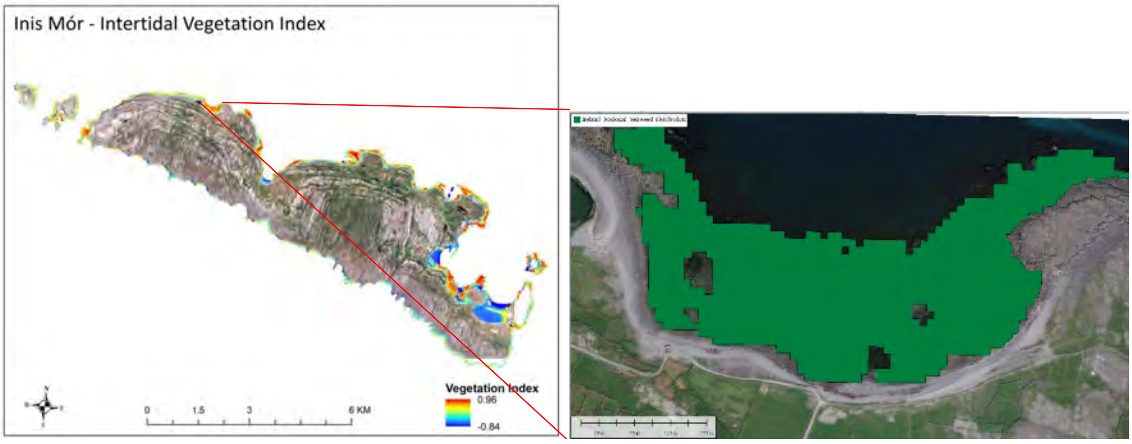


*Figure 6 Analysis of satellite imagery before the survey.*

Multispectral drone surveys were then conducted to define the composition of species present in the region of interest, with brown species being dominant with some presence of red and green algae. Image classification (fig. 7) was able to distinguish between *Fucus spp.* and *H.elongata*, which had visibly different structure and colours. Multispectral classification of other seaweed classes such as *H.elongata* and fucoids proved more complex due to their spectral similarities. In this case, a multi-segmentation approach of the images was adopted and the intertidal region was broken into three zones by depth: high, medium and low since different species occupy different part of the coastline. This approached proved successful in improving seaweed classes segmentation. Biological ground validation was conducted on these sites to validate image classification.


*Figure 7 Supervised classification of the bay in Inishmor. Good accuracy, confirmed by ground surveys.*

## Fathom

During the development of the SBIR initiative, Fathom conducted multi-site biological sampling and identification of seaweed resource in three primary locations.

- Kilkieran site (415,377 $m^2$) was chosen as a training site for the development of their neural network model. 750 biological samples were collected (fig. 8, 9).
- Roundstone (3,332 $m^2$) was used for model validation. 200 biological samples were collected (fig. 8, 9).
- Kinvara was also selected later on to further refine and validate the model. 72 data samples were collected (fig. 10).

The primary purpose of the biological sampling was to obtained accurate biomass data for Ascophyllum nodosum which was used for training, testing and validation of artificial neural network model. The predicted algorithm developed has the ability to both predicts the seaweed biomass, but can also be used for forecasting future harvesting at a particular site.


*Figure 8 Site location in Kilkieran and Roundstone.*

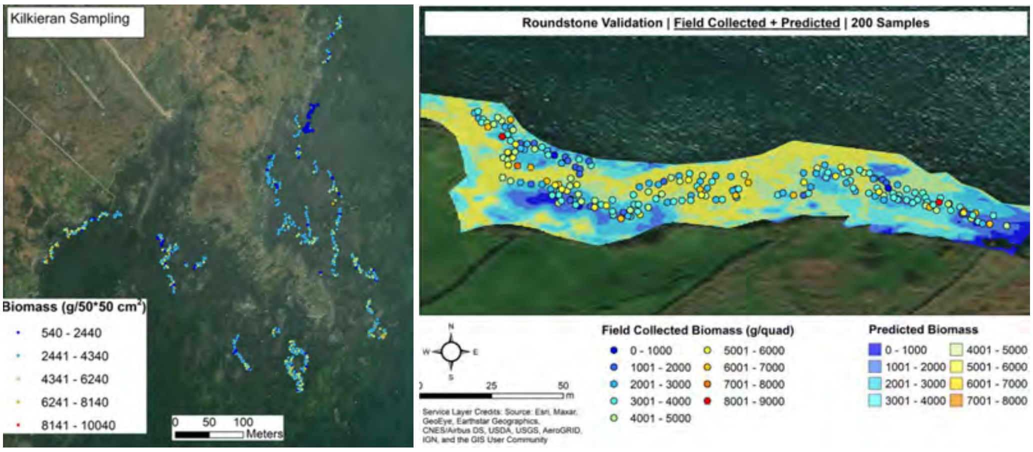


*Figure 9 over view of biological sampling completed in Kilkieran and Roundstone.*


*Figure 10 Overview of biological sampling completed in Kinvara.*

Site selection was based on the availability of suitable satellite imagery, potential access to the harvest site and proximity for the field crews. Ascophyllum nodosum, the target seaweed specie for Fathom, is harvested in all of these sites.

### TechWorks Marine.

During the initial phase of the SBIR initiative, TechWorks Marine partners visited two survey zones in Carraroe, Co. Galway with the primary purposes of assessing foreshore structure and composition to develop automated machine learning tools for seaweed classification. The primary survey zone was 52,755 m² (i.e. focused study area for data acquisition/processing of high-quality training datasets), whilst the secondary area was 207,918 m² (1km coastal corridor zone to illustrate potential scalability with long range UAV missions). Groundtruthing seaweed data were collected and used to validate the satellite and drone survey data. Fig. 11 shows the biological sampling completed by TechWorks (white dots).

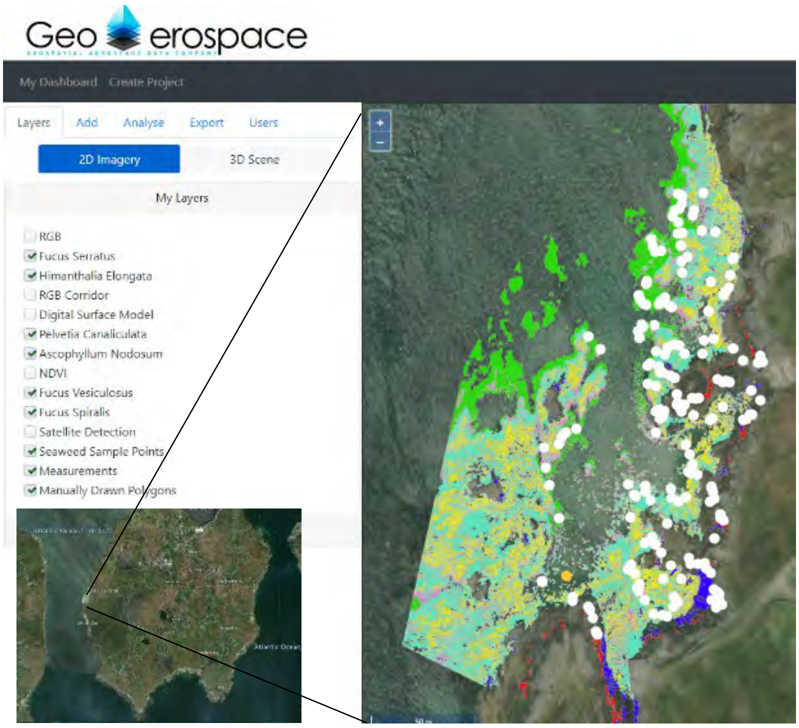


*Figure 11 TechWorks SBIR Phase 1 results showing classified seaweed species at the test site.*

The survey result showing classified seaweed species at the test site is provided below (fig. 12).

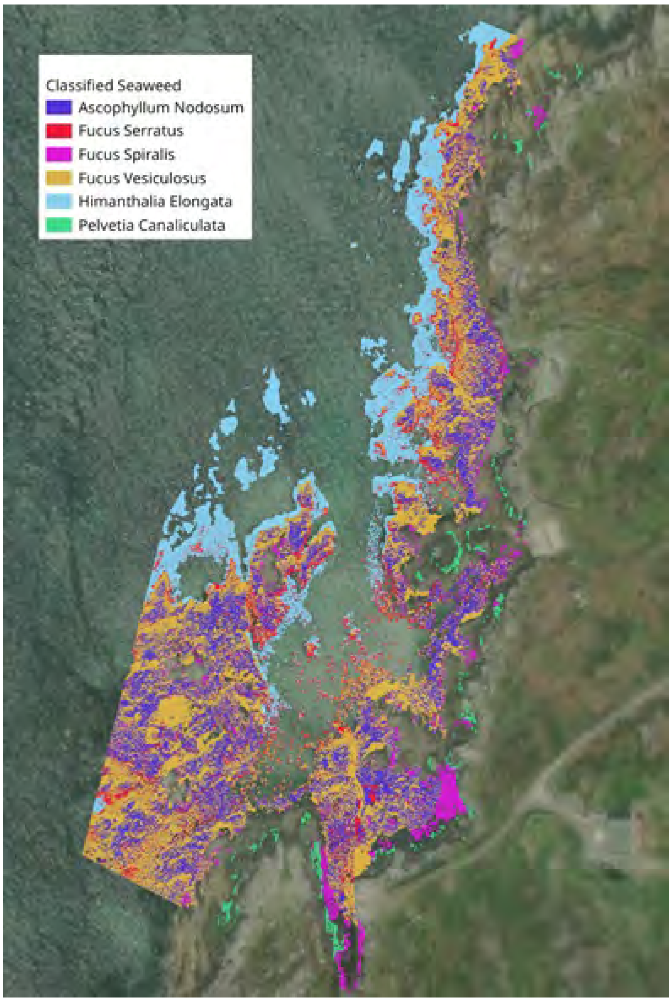


*Figure 12 Phase 1 results showing classified seaweed species at the test site*

### Spatial data products and maps demonstrating the seaweed resource in Ireland

One of the key outcome of the SBIR initiative was the creation of a National distribution map of Seaweed derived from free Satellite data. This task was completed by the AAT consortia in collaboration with Terra s.r.l., one of their project partners.

Terra s.r.l. developed the initial methodology which was based on use of complex algorithms and AI to analyse satellite data from the West coast of Ireland, including all the areas within a buffer zone of 750 m from the shoreline (fig. 13). The final report with detailed methodological processes is included in appendix 2.

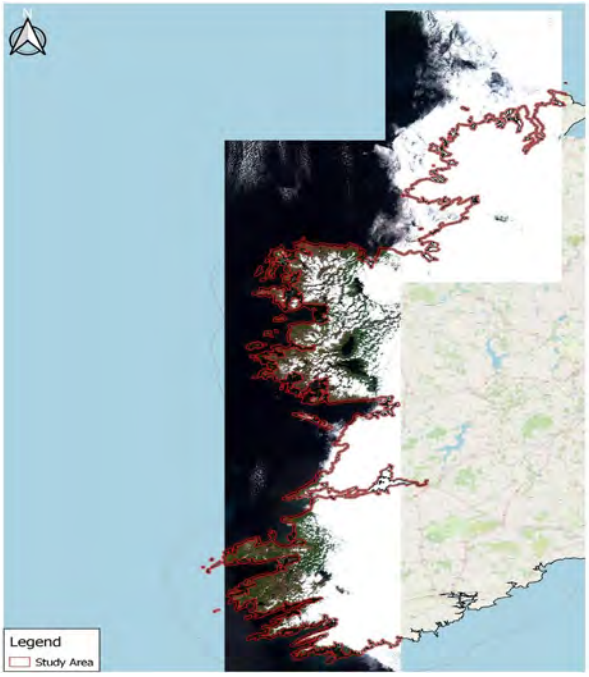


*Figure 13 Sentinel-2 True Colour Images Selected for the Day 28-05-2021*

AAT further refined this methodology and extended the analysis to the entire Irish coastline. Final GIS database of extracted seaweed distribution around the Irish coastline is showed in fig. 14 and included in GIS format in appendix 2.

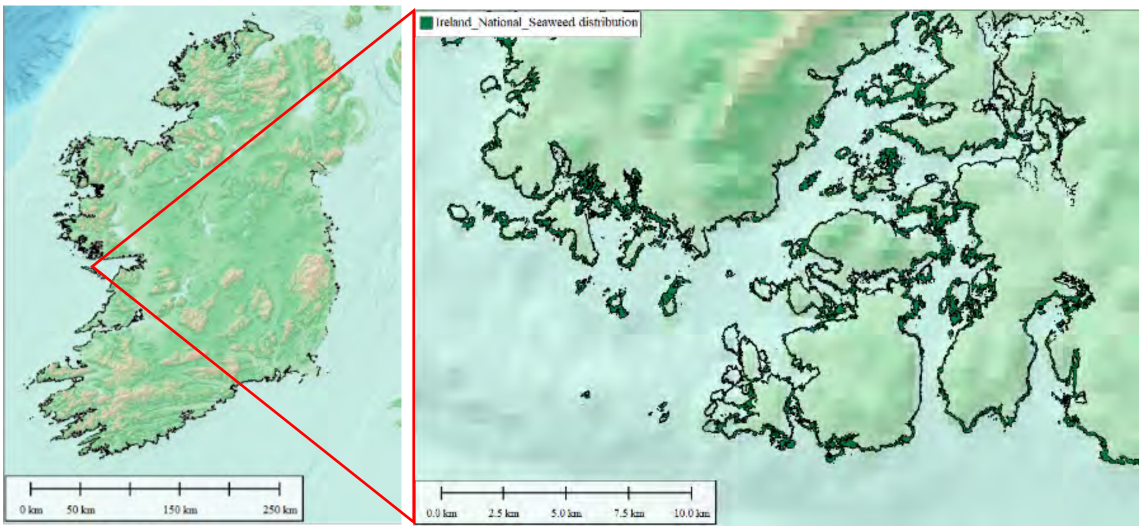


*Figure 14 Overview (left) and close up (right) of the extracted seaweed distribution around the Irish coastline*

Fig. 14 shows details of the raster map produced where extent of coastal seaweed is reported.

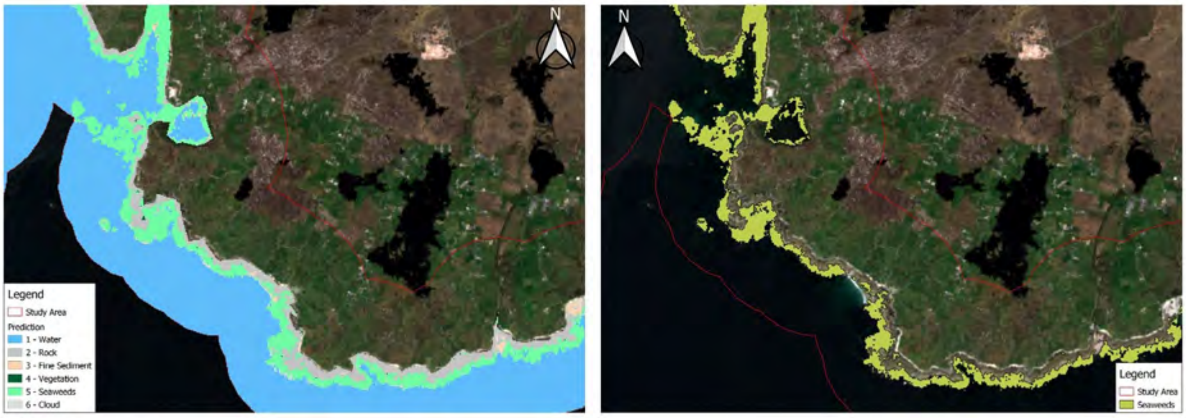


*Figure 15 National seaweed prediction maps.*

The results obtained showed that the AI based approach combined with high temporal free Satellite data (available daily) can be used to routinely monitor the presence/absence, spatial distribution and evolution of seaweed along the entire coast of Ireland.

In particular, this approach could be used for:

- Seaweeds distribution monitoring as a support for national and local manager that need to gather all possible ecological information and trend analysis.
- Commercial subjects, interested in seaweeds harvesting operations. This algorithm can support them in logistic planning and in monitoring the harvesting effect.

## Project timelines and key milestones achieved

- Q1-2019 > EMFF Funding allocated
- Q2/Q3 2019 > Market analysis of available commercial services capable to deliver seaweed mapping services resulted in realisation that very limited commercial services did exist at the time in Ireland. This lead to a re-focus of the project toward the development of these services. Consultation with Enterprise Ireland initiated
- Q4 2019 > Submission of proposal to Enterprise Ireland taking advantage of SBIR Ireland Competitive Call
- Q1 2020 > EI SBIR project awarded
- 06-2020 > Marine Institute, in collaboration with Enterprise Ireland launched a new Small Business Innovation Research (SBIR) biodiversity E-Tender challenge. The focus of the challenge is to develop novel, technology based, solutions to improve the way coastal intertidal seaweed resources are mapped in Ireland.
- 08-2020 > Marine Institute launch a E-tender for the procurement of a hyperspectral camera and drone.
- 09-2020 > SBIR tender close. Three companies awarded SBIR phase one project scoping fund.
- 12-2020 > SBIR phase 1 review. Two companies progress to SBIR phase two project development.
- 12-2021 > SBIR initiative end. Companies deliver their final report and focus on commercialisation of their technology solutions.
- 12-2021 > EMFF project completed.

## Final considerations

The Socio-Economic Study of Seaweed Harvesting in Ireland published by Marine Institute (2022) highlighted how the existence and growth of the Irish seaweed industry is dependent on the sustainable management of seaweed resources in coastal waters.

One of the many tools that can be implemented in order to sustainably exploit this resource is via the establishment of monitoring programmes (hosted by either academic or government institutions such as the Marine Institute) to enable harvesters, processors and regulators the opportunity to assess the status of the proposed harvesting areas by documenting the types and abundance of species present and evaluate the level of biodiversity present. A key element of a monitoring program should be the ability to deliver accurate and fast assessments for large areas or entire counties. None of the traditional seaweed survey methods can achieve this. Embracing and developing new methodologies based on latest multi-hyperspectral sensors deployed either via satellite or drones is the only way to achieve the required spatial and temporal accuracy.
The methodologies and workflows tested by the SBIR consortia can document the extent and abundance of seaweed resources, monitor pre and post harvesting and record damage done by harvesting as well as the regenerative rate of seaweed plants in harvested areas.
Where a coarser analysis is sufficient, a fully automated approach such as the one developed by Fathom could suffice as a tool to assess and monitor large areas and provide baseline data to users and regulators. When higher spatial and spectral resolution data are required, for example when individual species needs to be identified and monitored, on the ground drone or aerial surveys will be required until a time when satellite derived data can provide higher data qualities. While these surveys tend to be more complex, the SBIR consortia and in particular AAT have demonstrated that the use of fixed wing drones coupled with ad-hoc multispectral camera can map very large areas of the shoreline in just few days, making regional mapping and monitoring a reality while retaining the ability to discriminate among individual species or at least seaweed groups.
Scalability of these approaches was also analysed and tested both from a data collection and analysis view point. Combining drone flying automation and cloud computing power is at the key of scalabilities. Large drones capable to fly for many hours in full autonomy and map hundreds of km of coastline daily are already a reality in other Countries and in development in Ireland in particular as part of various R&D projects within Limerick University group. Once a reality, on board hyperspectral cameras will be able to collect all the required data needed to monitor multiple environmental parameters both along the shore and elsewhere.

While analysis of multispectral data is still achievable using standard IT infrastructures, analysis of hyperspectral data for large areas will require advanced cloud computing implementations coupled with ad-hoc machine learning (ML) and artificial intelligence (AI) algorithms, in particular when rapid data analysis and reporting is required. Available cloud based services such as Amazon AWS or Window Azure do offer great platforms where dedicated solutions such as the one developed by Fathom can be developed. These new solutions once fully implemented can resolve ongoing data management, analysis and reporting bottlenecks.

It is also undoubtful that while hyperspectral remote sensing will eventually replace multispectral one due to their higher spectral resolution and species discriminating abilities, more research is required in this area in order to understand the full potential and the limitations of this technology in the context of intertidal sea weed mapping and document if these sensors can address some of the challenges outlined below:

- Distinction between similar looking brown algae remains challenging; multiple previous researchers were able to classify between red, green and brown algae, or green algae and substratum, or between seagrasses, green algae and sand/sediment (e.g. Casal et al 2012, 2013).
- Same species can look different at different times of the year and at different locations (colour changes according to water quality and seasonal light climate) possibly requiring the creation of ad-hot spectral libraries based on seasonality and location.
- Discrimination of similar looking species when they are not spatially separated on the shore.
- Spectral profiles may also be different depending on wet or dry – e.g. measured immediately after tide goes out or after 1-2 in dry and windy conditions.
- Spectral libraries need to be established for the same species taken from different locations to integrate the range of spectra presented by an individual species.

The hyperspectral camera infrastructure procured under this funding scheme, the new PhD project recently advertised and the new collaboration with Limerick University will hopefully progress this topic of research further.

To conclude, the work carried out under this Blue Growth and Marine Spatial Planning Scheme has substantially helped to progress the Development of Methodologies for Assessment of Ireland's Seaweed Resource. Funding was used to stimulate research and discussion among numerous academic organisations and the SME sector. Extensive field work was conducted, portions of the Irish coastline was surveyed with drones (~2%) and hundreds of seaweed samples were collected. While this was only a snippet of the entire seashore, it allowed companies to prove their methodologies, test and fine tune drone and sensors, validate satellite data quality and develop the correct data analysis, machine learning algorithms and reporting methodologies. The project was also presented at various regional and national events, increasing awareness of the need to manage this resources correctly in the future.

## Appendix 1 – Submitted proposal details

Development of Methodologies for Assessment of Ireland's Seaweed Resource

### Project Overview and Objectives

Through the on-going marine planning process, the Irish Government identified that the sustainability of seaweed natural resources underpins the licensing regime for seaweed harvesting. The aim of this project is to develop a better understanding of the Irish seaweed resource around the Irish coastline, which will contribute to a biomass assessment for certain types of seaweed. Ascophyllum Nodosum is the primary species harvested. It grows on rocky surfaces near the seashore and is harvested by hand at low tide. Small amounts of other species are also harvested. The objectives of this projects are to:

- Develop methodologies for assessment of Ireland's seaweed resource distribution and biomass assessment using novel field techniques;
- Determine how pilot biomass assessment studies can be used to inform broad scale assessments of the resource;
- Undertake biological groundtruthing of relevant sites;
- Map seaweed species & coverage distribution and relate this to environmental, geographical, and seasonal variability;
- Understand current knowledge on the distribution of macroalgae.

### Issues and Rationale for project:

In Ireland, 25,000-30,000 tonnes of wild seaweed are harvested annually. It is a raw ingredient for high value cosmetics, biopharmaceuticals and food. The aim of this project is to develop standard methodologies for resource distribution and biomass assessment (where feasible), which will ensure the sustainable development of the sector and minimise environmental impact of the activity. Assessments will target achieving a better understanding of sustainable levels of harvesting, including assessment of operational sites where feasible.

### Costs to be funded by EMFF

Technical experts for Project 10: Development of Methodologies for Assessment of Ireland's Seaweed Resource will be funded to provide a better understanding of the status of the Irish seaweed resource, and develop refined assessment approaches, and methodologies for application around the Irish coastline to determine species diversity, distribution, and biomass. Specifically, costs of this project will support:

1. Methods development for scalable intertidal and subtidal seaweed resource assessment, with associated pilot field studies. Subtasks of this work will include:
    a. State of the art airborne hyperspectral studies (via drone and/or aircraft), with complimentary calibration and ground-truthing to:
        - best characterize seaweed resources;
        - assess their seasonal variability;
        - investigate regrowth rates;
        - assess confidence in survey repeatability and scalability; and
        - determine logistical & technical scalability factors in transitioning from site-specific to regional assessment approaches.

    b. An evaluation of the applicability and validity of existing regional acoustic and optical data resources for application to sub-tidal seaweed resource assessment, with the development and documentation of data analytics and methodologies, where appropriate.
    c. Small scale acoustic and video surveys of kelp will be undertaken with associated environmental ground-truthing (e.g., light penetration) to:
        - assess distribution extent / constraints of kelp growth;
        - ascertain technology limitations for detailed site assessment and monitoring; and
        - develop new methodologies, as needed.
2. To understand the potential commercial value of Ireland's seaweed resource, a biomass assessment is needed. A scalability study is therefore proposed to gauge how survey methods and technologies can be

scaled up for seaweed biomass assessment. Using the field results and methodologies developed in part 1 of this project, broad scale assessments of the resource will be developed where appropriate data are available, and guidance will be provided to support future capture of required information. Specific sub-tasks of this work would include:

   a. A literature review of the currently recognized macroalgae (incl. kelp) distribution in Ireland;
   b. On-the-ground surveys of relevant sites (e.g. sites with license applications) by a seaweed ecologist to:
      i. assess biomass information;
      ii. refine ground-truthing methodologies; and
      iii. determine reliability of reported and/or mapped resource assessment.
   c. Extraction of seaweed species and coverage distribution extents from the hyperspectral data, taking into consideration environmental, geographical, and seasonal variability constraints—to the degree achievable;
   d. Generation of spatial data and map products that record the current distribution of the seaweed resources assessed;

3. The procurement of a hyperspectral and/or acoustic sensor for 3rd party deployment on drones/aircraft and/or vessels respectively to underpin survey requirements outlined in parts 1 and 2 of the project as described above. Note: The above project will be provided by external contractors.

### Measurable Outputs

- A scalable survey methodology for seaweed resource assessment;
- Completed hyperspectral and acoustic studies of seaweed resource;
- Completed multi-site biological sampling and identification of seaweed resource;
- Broadscale site specific seaweed species & coverage distribution;
- Spatial data products and maps demonstrating the seaweed resource in Ireland

### Expected Benefits

This project will develop standard methodologies for assessing the seaweed resource around the Irish coastline, incorporating refinement of existing resource assessment approaches, data analytics methodologies to extract relevant information from existing data resources, and new scalable survey approaches. In certain areas, seaweed extraction is a source of public concern; this project will address these concerns by providing robust science to inform stakeholders. It will generate baseline field information towards addressing gaps in governance knowledge. Thus, project outcomes will be useful to support licencing decisions for seaweed extraction and monitoring of future harvesting.

## Appendix 2 – Report and data delivery

- AAT final SBIR reports
- Terra s.r.l final SBIR report – Seaweed atlas
- Vector data containing the extracted distribution of Seaweed around the Irish coastline

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