SUMMARY REPORT

Total Ecosystem Management of the InterTidal Habitat (TEMITH)

Image courtesy of Channel Coastal Observatory.

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EUROPEAN SPACE AGENCY CONTRACT REPORT

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1. INTRODUCTION

1.1. Purpose of the document

This activity was carried out in the framework of the European Space Agency's (ESA) Earth Observation (EO) Science for Society Programme.

ESA's EO Science for Society is one of the core activities of the Earth Observation Envelope Programme (EOEP) which is the backbone for implementing the ESA Earth Observation Strategy 2040. It aims to benefit society by developing and providing observations to better understand our planet and monitor its health, enabling improved predictions of the physical interaction of society with the Earth system, and informing decision makers and citizens on scenarios and consequences of political and economic decisions regarding our home planet.

This document is the summary report of the project. It summarizes the work which has been performed and its achievements. It intends to address a broad audience outside the project.

1.2. Objective of the project

Protection of coastal habitats at local, national, and international levels is critical to maintaining their function and the consequent ecosystem services and goods they provide, however, budgets for conservation and management are nearly always limited. Traditional methods for managing exploited stocks (i.e. fisheries) have been based on single species systems, but in recent years achieving sustainable exploitation of coastal ecosystems is now seen to require ecosystem-based approaches, termed here as Total Ecosystem Management (TEM). TEM requires extensive habitat monitoring and assessment of the threats, but currently, data for intertidal areas are usually not collected; are difficult to access; in unsuitable formats or not easily visualised in a holistic way. Thus, agencies make habitat assessments and management decisions in an inefficient and costly way, without access to the best available evidence.

There is a need for cost-effective means of environmental monitoring and assessment, including that of intertidal habitats in busy coastal areas that are impacted by multiple user groups. A review has been conducted to provide an assessment of the current state of art for the following methods: biotope walkover surveys; Unmanned Aerial Vehicle (UAV) or drone flights; aerial photography; Closed Circuit Television (CCTV) systems, and satellite imagery for intertidal habitats.

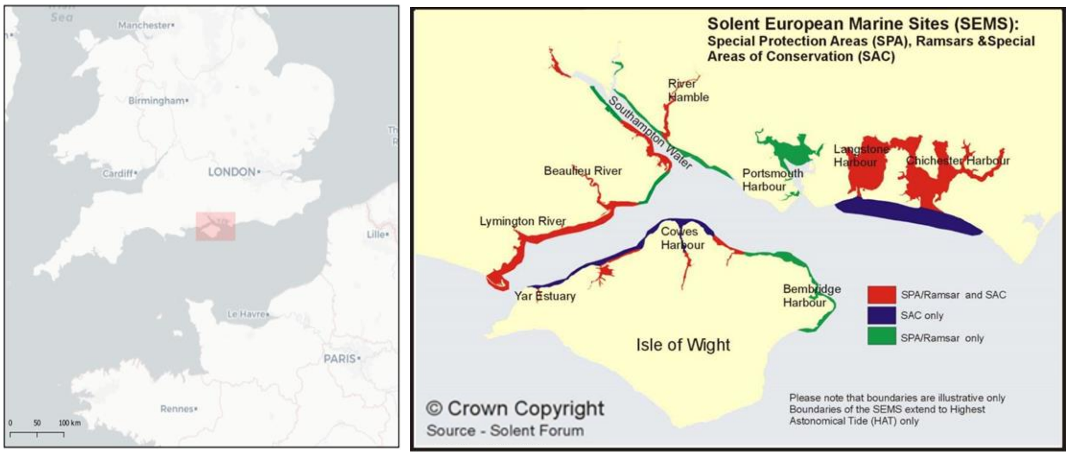


Figure 1. Maps of the area of interest: The Solent, South of England. This region is one of the most protected and exploited intertidal regions in the world. Though it only covers 150 km^2 is an example of the multi-user and complex management structures typical of intertidal habitats across the world.

Four pressures were first identified in the scope of the project: sediment disturbance due to human activities such as fishing, dredging, bait collection and inshore boat use; harmful algal mats; sewage plumes; and litter accumulation. As the project progressed, the decision was made to focus model development on sediment disturbance and algal mats, as not enough ground truth was available for sewage plumes without an extended ground survey, and litter accumulation is already explored in many other projects.

The Total Ecosystem Management of the InterTidal Habitat (TEMITH) project aimed to design and prototype a solution to monitor pressures in the intertidal habitat in the Solent region, South of England (Figure 1) using EO data in addition to existing sources of information.

1.3. Organisation of the project

Two partners are involved in the project:

deimos elecnor group	• Deimos Space UK Ltd is the UK subsidiary of Elecnor Deimos, a well-established group of companies in the European aerospace sector with experience in Remote Sensing and GNSS Location Services. • Deimos Space UK is the prime contractor of the project. Deimos provides the back-end of the system which collects and processes the imagery, system design and platform preparation, and deep learning expertise for object detection.
UNIVERSITY OF PORTSMOUTH	• The University of Portsmouth Institute of Marine Sciences provides more than 70 years of extensive expertise in ecology, biology, fisheries and conservation, oceanography, climate change and pollution. • The University of Portsmouth (UoP) is the subcontractor of the project. UoP engages with prospective end users through existing professional networks, enabling identification of relevant datasets available for model training, collection of user requirements, and dissemination of information about TEMITH. UoP's ecological expertise and experience with analysing remotely-sensed data supports production of new datasets and evaluation of TEMITH outputs.

With a statutory duty to protect and conserve intertidal habitats, Natural England (NE) and the Southern Inshore Fisheries and Conservation Authority (SIFCA) are also key partners associated with the project as key stakeholders and potential end users. Input from these organisations is critical for ensuring that the platform developed is relevant to the needs of prospective end users.

2. User Requirements Collection

2.1. End user survey/workshop (April 2019)

A survey was sent to named individuals within 11 relevant organisations and structured interviews of key Natural England (NE) and Southern Inshore Fisheries and Conservation Authority (SIFCA) staff were carried out within a dedicated end user workshop (April 2019). Key themes included 1) most important impact/stressor on intertidal environment (of sediment disturbance, algal mats, nutrient plumes and litter), 2) coverage and data needs, 3) data usage and role, 4) data access method, 5) payment level and process. Twelve individuals completed the survey via the workshop or online with the majority working for government agencies.

Resulting recommendations: Focus on sediment disturbance, algal mats and nutrient plumes priorities, but incorporate structures and moorings if possible; data should be generated at the regional and site level; data will have multiple and overlapping uses, but must be of high quality and should be provided with associated levels of confidence; the platform should be web based and accessible remotely; usage will be regular and infrequent, but may change rapidly for each user; payment methods should be flexible and respond to end user type as well as the broader EO market.

2.2. Discussions with critical partners and other organisations (Sept 2019/Feb 2020)

Structured discussions with eight representatives from critical partner organisations NE (local/national representatives) and SIFCA, and from Sussex IFCA (whose district covers Chichester Harbour in the Solent), were carried out by phone in Sept 2019 and Feb 2020. The discussions served to provide an overview of the proposed platform and to further identify user requirements with respect to 1) intertidal monitoring, including relevance of the prioritised features (sediment disturbance – shellfish dredging, digging, boat scars), algal mats, and nutrient/wastewater plumes), 2) technical aspects of the platform and outputs, and 3) subscription and cost.

Distinguishing from other types of intertidal vegetation was nested in the detection of algal mats, however feedback indicated the relevance of habitat extent determination for seagrass and saltmarsh (habitats of conservation value). Disturbance to seagrass was also of particular interest. Seagrass and saltmarsh detections were therefore considered for TEMITH model training, but at a lower priority than algal mats. Other requirements/interests identified from these discussions were:

Model and platform capabilities: Include drone imagery upload and classification feature on platform; ability to export from platform and upload own data to platform; determine extent; track habitat extent *and* change, determine change from user's own data; use of satellite to corroborate vessel monitoring system (VMS) and observations - compare in platform; seagrass extent *and* cover; distinguish new scars from old scars; determine number of diggers per unit time; quantify anchoring; detect disturbance in seagrass; broader geographic coverage.

Frequency: Higher frequency may be required to assess risk (e.g. fisheries non-compliance) or to quantify irregular wastewater discharge events. Lower frequency may be required for post-summer or seasonal assessments of disturbance or to feed into multi-year condition assessments of protected features.

Output requirements: Spatial resolution required defined by objective; sub-meter/meter resolution reasonable (could be habitat gradients within 10m). Raster and shapefile outputs compatible with ArcGIS should be provided.

Cost/Subscription: Consider options for a shared cost model (complementary roles played by multiple organisations); frequency of service use may differ for national vs. local teams - one-off payments as needed may be more appropriate for local teams; key considerations are cost/time to perform in-house analyses vs. using the platform; if priced per km^2, relevant is how much of a site (e.g. protected area) is covered.

2.3. Evaluation Workshop (Oct 2020)

A virtual Evaluation Workshop (EVW) was held with 19 participants to collect objective feedback on outputs and the utility of the proposed platform. The participants represented Solent stakeholders and organisations with interest in intertidal habitats and/or roles in intertidal data collection, monitoring, conservation, management in the Solent or at the national level (including England, Scotland, and Wales) as well as Earth Observation specialists. Many participants were from government sponsored bodies. The workshop focused on modelled outputs for intertidal vegetation (algal mats, seagrass, saltmarsh) and for sediment disturbance (digging, shellfish dredging, boat scars). Potential plumes detected from satellite imagery were not readily distinguishable as wastewater plumes and so this feature was not included for further model training and evaluation. The workshop materials included circulation of a pre-recorded webinar, questionnaire, access and guide to a data server for deeper consideration of the outputs, training dataset details, and later circulation of example outputs from the server.

Follow-up small group discussions, guided by the questionnaire, were held via Zoom from October 6-9, 2020. The questionnaire covered: TEMITH output applications and quality, required format and software compatibility, required frequency, payment for EO products, and other relevant EO products. User requirements identified during the workshop and from discussions with NE and SIFCA in preparation of the EVW (July 2020) are presented below:

Model and platform capabilities: Statistical analyses (e.g. % change) on the platform, not just maps; detect range of vegetation densities; accurately detect vegetation classes and distinguish from others with similar signals; detect in combination (vegetation types and sediment disturbance in relation to vegetation); include drone imagery upload feature; others of interest were underwater detections and resolving sediment scarring age.

Satellite acquisition and frequency: Ability to task satellites for low tide compatible times within a given period of interest; majority required once per year for vegetation outputs with uncertainty and higher frequencies indicated for disturbance.

Required information and outputs: Indication of margin of error; provide image to visualise with classified outputs and date/time of image; raster and shapefile both required; outputs must be ArcGIS compatible, but QGIS, AutoCAD, MapInfo also used.

Cost: Key considerations are affordability, cost relative to map accuracy, and the potential for savings in collecting data that can be used for multiple purposes; high cost may inhibit individual case by case use where limited budgets are a concern; cost in terms of MPA units may make more sense than per km^2 - relates to resource attribution.

Other relevant EO outputs (related to TEMITH): Habitat classification/change detection, habitat condition/quality and change detection; non-target vegetation class detection; activity participation; nationwide coverage; seagrass damage from mooring in shallow subtidal; anchoring; tracking emergency discharge wastewater plumes.

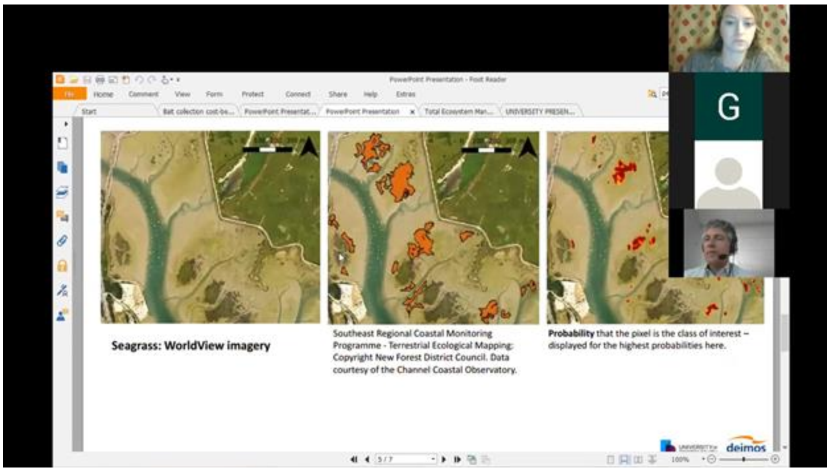


Figure 2. Screenshot from one of the Evaluation Workshop small group discussion sessions via Zoom

3. Data gathering and preparation

3.1. Satellite data gathering

Multiple satellite imagery data sources were considered for the detection of sediment disturbance and algal mat pressures in intertidal zones. Each individual in-situ dataset (presented in next section) recorded the date of collection and location information which was used for satellite data gathering.

Imagery considerations:

- **Sensor resolution for feature detection:** Two sensors were chosen for feature detection: freely-available Copernicus Sentinel-2 imagery at 20 m resolution and commercial, very high-resolution MAXAR WorldView, GeoEye and Quickbird imagery at 0.31 - 0.61 m resolution. Detection of sediment disturbance features required very high-resolution imagery. Other commercial sources of satellite imagery such as PlanetScope were considered, but MAXAR provided the highest resolutions.
- **Sensor revisit frequency:** Satellite imagery dates of acquisitions needed to be as close as possible to ground truth acquisition dates. To increase the possible availability of suitable imagery which covered the AOI, a window of 4 weeks (2 weeks before and 2 weeks after the ground truth acquisition date) was used, and extended to a maximum window of 8 weeks where no imagery was available. The window periods ensured specific threats could still be visible and distinguishable in satellite imagery.
- **Cloud coverage:** Cloud extents over the AOI were assessed to discover usable imagery. Images were disregarded where the presence of cloud or cloud shadow obscured direct vision to features.
- **Tide conditions:** Tide conditions were a key challenge in obtaining useful EO data. Visual assessment of tide conditions was carried out for each image as low tide was preferable to ensure features could be visible in the imagery.

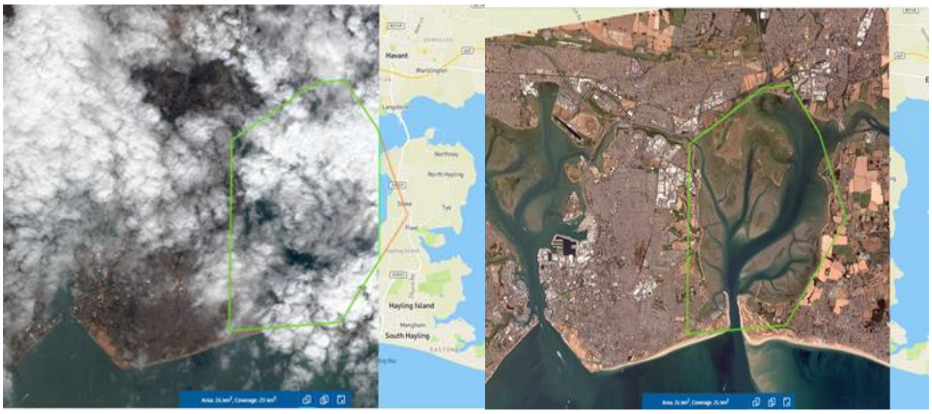


Figure 3. Example MAXAR imagery from https://discover.digitalglobe.com/ for Langstone Harbour which covered multiple in-situ datasets. These examples show the cloud coverage and AOI coverage considerations which had to be taken into account.

3.2. Sediment disturbance

The detection of intertidal sediment disturbance resulting from digging, shellfish dredging, and boat scars was prioritised. Mapped polygon datasets were of interest for model training and priority datasets were acquired for the Solent, Poole Harbour, and Wales (Table 1). Additional labelling of available drone imagery, Channel Coastal Observatory aerial photography (Table 1), and high-resolution satellite imagery (Table 2) was performed to produce more training data for each disturbance type. Key considerations in labelling were the morphology and context of the scarring. Where indicated, high confidence polygons were selected for model training.

Table 1. Datasets used to train models for digging detection from drone imagery/aerial photography. Number of sites/locations indicated may not have been used for each of the scarring types.

Imagery source	Labels source	Date	Type (res)	# Sites	Used in training
White, S., Schaefer, M., Watson, G. (2019). *Cost benefit analysis of survey methods for assessing intertidal sediment disturbance: a bait collection case study.* Report by the University of Portsmouth for Natural England, 64 pp.	**Digging** (White et al., 2019); **dredging and boats** (TEMITH manual labelling)	26-29/06/18	Drone ~2-3cm	3 (Solent harbours)	Yes
Copyright New Forest District Council. Image courtesy of the Channel Coastal Observatory.	**Digging** (White et al. 2019; TEMITH manual labelling);	18/08 and 23-24/08/16	Aerial photo 10cm	4 (Solent harbours;	Yes

https://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/.	**dredging and boats** (TEMITH manual labelling)			Southampton Water)	
Perrins, J., Lush, M., Taylor, T., Holt, R and Bunker, F. (2020). *Investigating the location and density of bait digging in Wales.* NRW Evidence Report Series Report No: 449, 170pp, NRW, Bangor. Contains Natural Resources Wales information © Natural Resources Wales and database right. All rights reserved.	**Digging** (Perrins et al. 2020); **boats** (TEMITH manual labelling)	09/19-11/19	Drone ~3cm	10 (Wales)	Yes
Fearnley, H., Cruickshanks, K., Lake, S. & Liley, D. (2013). *The effect of bait harvesting on bird distribution and foraging behaviour in Poole Harbour SPA.* Unpublished report by Footprint Ecology for Natural England, 125 pp.	**Digging** (Fearnley et al. 2013)	11/12-02/13	Drone ~6cm	1 (Poole Harbour)	Yes
Clarke, L. J., Hill, R. A., Ford, A., Herbert, R. J., Esteves, L. S., & Stillman, R. A. (2019). Using remote sensing to quantify fishing effort and predict shorebird conflicts in an intertidal fishery. *Ecological Informatics, 50*, 136-148	**Dredging -** not in a polygon format	23/11/15	Drone ~3.5cm	1 (Poole Harbour)	No (used in test)
Contains, or is based on, information supplied by Natural England. Terms of use:https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/775365/NE-terms-ofuse.pdf	**Boats** (TEMITH manual labelling)	03/10/18	Drone ~3cm	1 (Langstone Harbour)	Yes

Dredging scars identified during a 2018 UoP ground/drone survey provided a basis for identifying their morphology. Examination of CCO aerial photography in relation to the distribution of Solent fishing activities, correspondence with local IFCAs, and reference to SIFCA European Marine Site Habitats Regulations Assessments (with gear types and sightings maps) further fed into a familiarisation with scarring types and confidence assessments for dredging scars. Boat scars labelled included moorings, berth scars, keel drags, and 'independent'. The latter were consistent with boat scars, but independent of any mooring/structure or were in likely boat traffic areas, but not readily distinguishable as one of the types. Linear keel drags and dredging scars were distinguished using a confidence assessment.

Existing datasets and satellite imagery labelling were used to train models for detection from satellite imagery (Table 2). The former were linked to satellite imagery as close as possible to the collection date, however a maximum of 4 weeks away was deemed appropriate in the context of previous findings for the persistence of digging scars. The existing disturbance polygons were adjusted according to visibility in the imagery. Direct manual labelling of clips from additional satellite images was performed for images prioritised according to tidal exposure, site familiarity, availability of high-resolution imagery and, in some cases, existing polygon datasets to help ground-truth the labelling process.

Table 2. Datasets used to train models for detection of sediment disturbance from satellite imagery. The satellite (Sat.) imagery resolution (res) is pan-sharpened. Sensors are WorldView/WV, GeoEye-1/GE1, and QuickBird2/QB2. Locations (loc.) are harbours (Langstone/LH, Chichester/CH, Portsmouth/PH) and Southampton Water/SW.

Imagery source	Labels source/ scarring type	Loc.	Date	Sat. (res)	Sat. date
Aerial Photography - Copyright New Forest District Council. Image courtesy of the Channel Coastal Observatory (CCO). https://www.nationalarchives.gov.	Digging - White et al. (2019)	LH	18/08 and 23/08/16	WV3 (31cm)	23/08/16
		CH	23/08/16	GE1 (46cm)	23/09/16

uk/doc/open-government-licence/version/3/.					
N/A	Digging - Watson, G., Murray, J.M., Schaefer, M., Bonner, A., & Gillingham, M. (2013) *Does local marine conservation work? Evaluating management strategies for bait collection in the Solent.* A report to Natural England with funding from the Crown Estate's Marine Stewardship fund, 168 pp.	CH	14/09/11	QB2 (61cm)	19/08/11
Aerial Photography - CCO (row 1 for full reference)	Digging - TEMITH manual labelling	LH	18/08 and 23/08/16	WV3 (31cm)	23/08/16
N/A	Digging - TEMITH manual labelling - satellite	LH	N/A	WV2 (46cm)	27/06/16
		LH	N/A	WV2 (46cm)	09/08/19
		PH	N/A	GE1 (46cm)	14/09/17
N/A	Dredging - TEMITH Manual labelling - satellite	SW	N/A	GE1 (46cm)	14/09/17
		SW	N/A	WV2 (46cm)	06/06/14
Aerial Photography - CCO (row 1 for full reference)	Boats - TEMITH manual labelling	CH	23/08/16	GE1 (46cm)	23/09/16
		LH	18/08 and 23/08/16	WV3 (31cm)	23/08/16
Drone imagery - Contains, or is based on, information supplied by Natural England. Terms of use: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/775365/NE-terms-of-use.pdf		CH	03/09/19	WV3 (31cm)	04/09/19
Aerial Photography - CCO (row 1 for full reference)		SW	23-24/08/16	GE1 (46cm)	23/09/16
N/A	Boats - TEMITH manual labelling - satellite	LH	N/A	WV2 (46cm)	27/06/16
		SW	N/A	GE1 (46cm)	14/09/17

3.3. Algal mats, seagrass, saltmarsh

Mapped polygon datasets were prioritised for the development of the deep learning models used in TEMITH. Datasets for algal mats, seagrass, and saltmarsh were all searched to train models to distinguish types. Sources for priority datasets with polygons included Environment Agency, Hampshire and Isle Wight Wildlife Trust, Natural England, Channel Coastal Observatory, and Natural England/University of Portsmouth. The final datasets selected for model training by dataset suitability and availability of suitable satellite imagery (aimed for link with satellite imagery two weeks either side of the data collection date where possible) are presented in Table 3. Although not matched to the training data acquisition, the selected Sentinel-2 image was prioritised for model training because it was both cloud free and a low tide image.

Table 3. Algal mats, seagrass, and saltmarsh datasets used in training of models for detection from WorldView (WV) imagery and from Sentinel imagery.

Type	Labels source	Location	Date	Satellite (res)	Satellite date
Algal mats	Extent of macroalgae: Contains Environment Agency information © Environment Agency 2019	Pagham Harbour	03/08/18	WV3 (~2m)	23/07/18
		Southampton Water	09/07/13	WV2 (~2m)	13/07/13

Seagrass	Southeast Regional Coastal Monitoring Programme - Terrestrial Ecological Mapping: Copyright New Forest District Council. Data courtesy of the Channel Coastal Observatory.	Langstone Harbour	26/06/13	WV2 (~2m)	13/07/13
Saltmarsh	Saltmarsh Zonation: © Environment Agency copyright and/or database right 2015. All rights reserved.	Southampton Water	20-22/08/13	WV2 (~2m)	13/07/13
Saltmarsh	Solent Saltmarsh Zonation data: © Environment Agency copyright and/or database right 2020. All rights reserved.	Langstone Harbour	18/08 and 23/08/16	WV3 (~2m)	23/08/16
Merged	Saltmarsh Zonation: © Environment Agency copyright and/or database right 2015 and 2020. All rights reserved.	Solent, Pagham Harbour	2008, 2013, 2016	Sentinel 2 (20m bands)	30/07/20
	Southeast Regional Coastal Monitoring Programme - Terrestrial Ecological Mapping: Copyright New Forest District Council. Data courtesy of the Channel Coastal Observatory.	Langstone, Portsmouth, Chichester Harbours	26/06/13		
	Extent of macroalgae: Contains Environment Agency information © Environment Agency 2019	Southampton Water, Pagham Harbour	7/9/13; 03/08/18		

3.4. Wastewater plumes

Data gathering for wastewater plumes focused on data that could be used to identify and corroborate discharge events and their detection from satellite imagery. Southern Water provided duration data for stormwater/emergency discharges into Langstone Harbour (2017-2019). A preliminary satellite search was performed with respect to long-duration events, emergency discharges, and events in the media to look for visible evidence of a plume, but potential evidence was minimal. The search was expanded to the two other eastern Solent harbours and Sandown Bay off of the Isle of Wight. Additional resources fed into a process of discharge prioritisation for these areas and identification of relevant dates to search in the satellite imagery corresponding with key discharge locations (relative to peak river flow dates, events in the media, higher than normal water bacteria counts). Resources considered included Environment Agency water quality data, nitrate vulnerable zone reports, hydrological data, consented discharges locations; National River Flow Archive flow statistics; Chichester Harbour Conservancy/Chichester District Council water quality assessments; Centre for Environment, Fisheries and Aquaculture Science Sanitary Survey reports; real-time/near real-time water temperature sources (CCO wave buoy; Chimet/Cambermet/Sotonmet/Bramblemet); and online media. A search of Sentinel and DigitalGlobe satellite imagery was performed, with some potential plumes identified, but these could not be confidently corroborated as wastewater plumes to support model training.

4. System design and platform preparation

4.1. System requirements and design

Typical use cases were identified in order to define the interactions between the different roles and the system to achieve the project's objectives. Figure 4Figure 1 describes an example of how the TEMITH Data Service can be used.

Key services are:

- Collection of satellite EO data from various providers
- End-users can operate UAVs to acquire very high-resolution images to replace satellite imagery when unavailable, or to obtain higher resolution imagery.
- TEMITH Data Service processes all EO data in order to support the generation of derived products for the detection of pressures for intertidal zones.

- Products generated by TEMITH Data Service are accessed by the user with a web based front-end, where they can be downloaded or visualized.

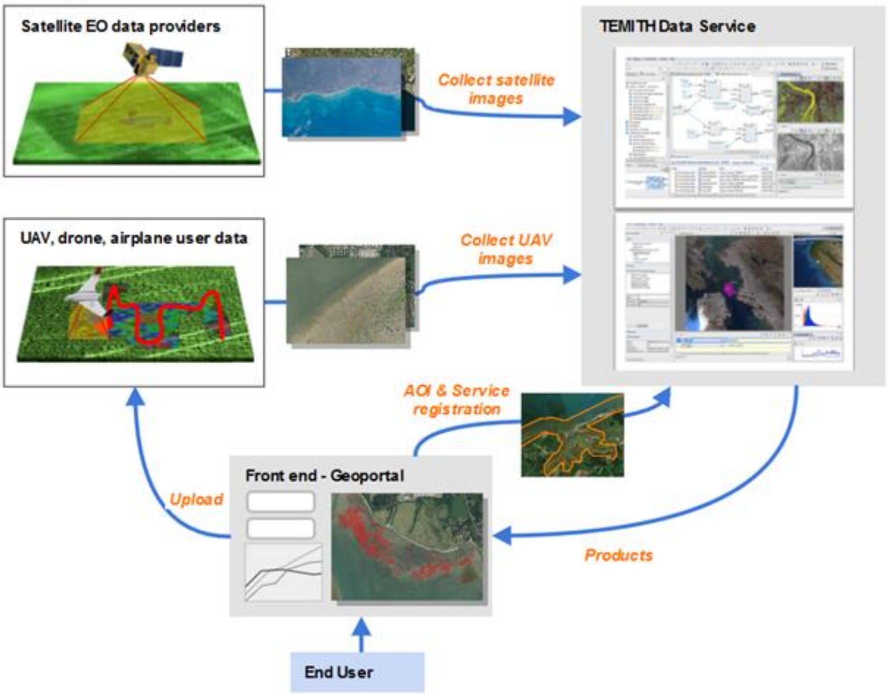


Figure 4. Illustration of TEMITH Data Service usage and platform

4.2. Algorithm development

Two different kinds of techniques have been considered for the detection of threats to intertidal zones using EO data. The first one is based on the computation of indexes derived from the pixel values across the multispectral bands of the images. This kind of algorithm can help to detect target features made of materials with specific spectral reflectance properties that have been measured with a spectrometer in-situ or in a laboratory. When this can achieve good performances for specific applications like algal blooms detection, where chemical composition of the feature is distinct from its surrounding environment, it is less suitable when looking at structural features like boat scars and digs on intertidal sediments. The second kind of technique relies on the use of supervised machine learning, and belongs to the area of computer vision.

Convolutional Neural Networks (CNN) are a type of Artificial Neural Networks (ANN) that are specialized for computer vision tasks. They are considered state-of-the-art techniques for semantic segmentation, and a lot of research on the subject has been ongoing since 2010 for various kinds of application. The well-known CNN architecture called "U-net" has been selected as a base model for the detection of threats to intertidal habitat.

The amount of training samples required for CNN and deep learning is usually very important. For a project such as TEMITH, the amount of training data that can be gathered is usually not enough to obtain a robust deep learning model. To cope with this issue, transfer learning technique has been applied. For the detection of features such as algal mats, seagrass, and saltmarsh, it has shown useful to compute some indexes such as GNDVI, NDVI, and RedNDVI. These were then directly used as input to train the models. For the detection of algal mats, seagrass, and saltmarsh at lower resolution (Sentinel-2), a random forest model was used instead of U-net, as the amount of available ground truth for this sensor was very limited. Separate models were trained depending on the intertidal pressure to detect and the spatial resolution, as shown in Table 4:

Table 4. Summary of model training for each pressure and resolution

Models training			
Type of sensor	**Intertidal pressure**	**Model**	**Input bands**
UAV-AIR	Digging	U-net with efficientnetb4 backbone pretrained on imagenet (transfer learning)	R, G, B, A
	Boat scars	U-net with efficientnetb4 backbone pretrained on imagenet (transfer learning)	R, G, B, A
	Dredging	U-net with efficientnetb4 backbone pretrained on imagenet (transfer learning)	R, G, B, A
High resolution satellites	Digging	U-net with efficientnetb7 backbone pretrained on imagenet (transfer learning)	B, G, R, NIR
	Boat scars	U-net with efficientnetb7 backbone pretrained on imagenet (transfer learning)	B, G, R, NIR
	Dredging	U-net with efficientnetb7 backbone pretrained on imagenet (transfer learning)	B, G, R, NIR
	Algal mats	ResU-net	GNDVI, NDVI, RedNDVI
	Seagrass	ResU-net	GNDVI, NDVI, RedNDVI
	Saltmarsh	ResU-net	GNDVI, NDVI, RedNDVI
Sentinel 2	Algal mats	Random Forest	B, G, R, NIRx2, Red Edge
	Seagrass	Random Forest	B, G, R, NIRx2, Red Edge
	Saltmarsh	Random Forest	B, G, R, NIRx2, Red Edge

Detection of sediment disturbance from satellite was restricted to high resolution satellite imagery (at sub-meter resolution with pan-sharpening). The drone/aerial photography models were trained with imagery with a resolution of 10cm or less.

4.3. Results

Model performances are presented in the form of tables, where different metrics are displayed depending on the algorithm used, as well as output maps examples.

Table 5. Model performance metrics for sediment disturbance (Efficientnet-U-net models)

Sediment disturbance - metrics		Target Feature & Background		Target Feature only	
Type of sensor	**Intertidal pressure**	F-Measure	Validation F-Measure	F-Measure	Validation F-Measure
UAV-AIR	Digging	0.68	0.91	0.91	0.9
	Boat scars	0.71	0.93	0.89	0.87
	Dredging	0.72	0.95	0.95	0.94
High resolution satellites	Digging	0.7	0.92	0.86	0.62
	Boat scars	0.72	0.97	0.82	0.67
	Dredging	0.65	0.94	0.55	0.78

Table 5 shows results for sediment disturbance features. With a higher validation f-measure, the drone/aerial imagery models perform better than the satellite models. One of the challenges for training the satellite models was the amount of data available. Where ground-truth labels existed for the UAV models, satellite imagery could not always be found for the corresponding date. It also often suffered from limited visibility of the shore due to clouds or the tide and ground truth applied to the satellite imagery often needed to be adjusted. Improvements would be achieved with prioritizing the direct labelling of cloud-free and low-tide satellite images. To ensure confidence, this should be limited to known areas with disturbance activities that have high resolution imagery available to ground truth the satellite image.

While it is important to consider the outputs in the context of the amount of training data used, in particular for the satellite models, which may limit the current ability to generalize to new locations or images, the feasibility of using CNNs to detect sediment disturbance at the pixel level from aerial imagery and sub-meter satellite imagery is demonstrated.

Dredging – UAV-AIR model

Image: Copyright New Forest District Council. Image courtesy of the Channel Coastal Observatory

Ground truth: TEMITH manual labelling

Dredging– Satellite model

Image: WorldView-02

Ground truth: TEMITH manual labelling

Digging – UAV-AIR model

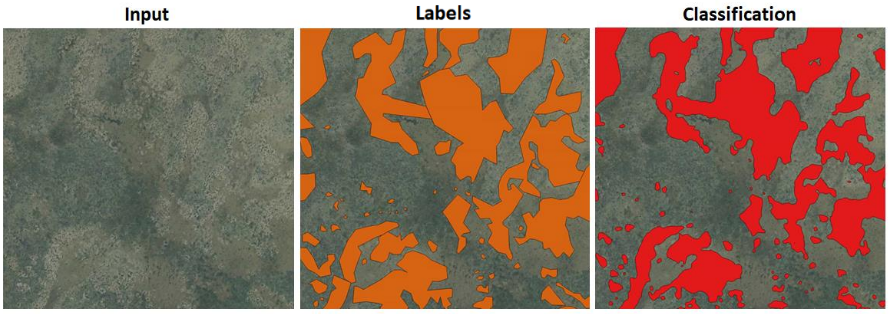


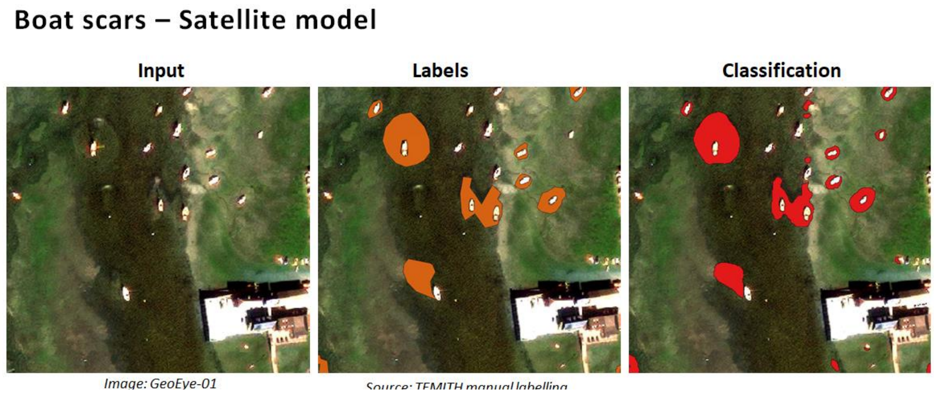
Image: Copyright New Forest District Council. Image courtesy of the Channel Coastal Observatory.

Ground truth: White et al. (2019). Cost benefit analysis of survey methods for assessing intertidal sediment disturbance: a bait collection case study. Report by the University of Portsmouth for Natural England, 64 pp.

Digging – Satellite model

Image: WorldView-03

Ground truth: White et al. (2019). Cost benefit analysis of survey methods for assessing intertidal sediment disturbance: a bait collection case study. Report by the University of Portsmouth for Natural England, 64 pp.



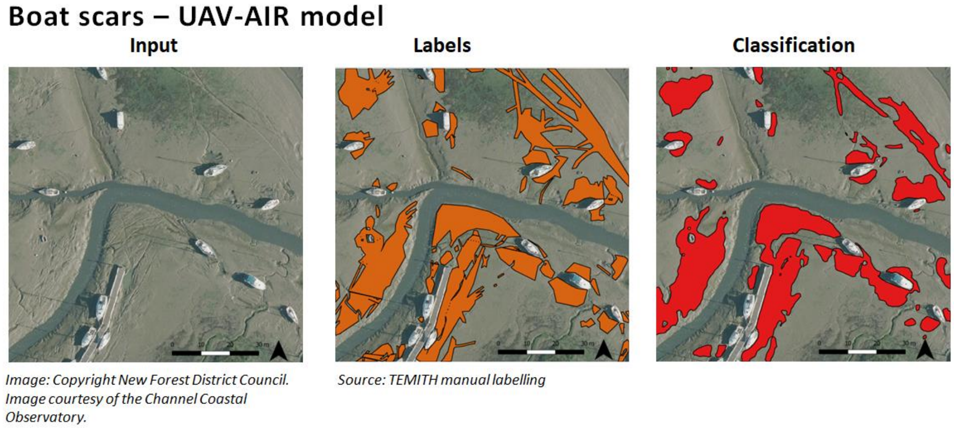


Table 6 shows model performances for the detection of algal mats, seagrass and saltmarsh on high resolution satellite imagery.

Table 6. Model performance metrics for algal mats, seagrass and saltmarsh (ResU-net models) on high resolution satellite imagery.

Models training		Validation F-measure
High resolution satellites	Algal mats	0.91
	Seagrass	0.82
	Saltmarsh	0.95

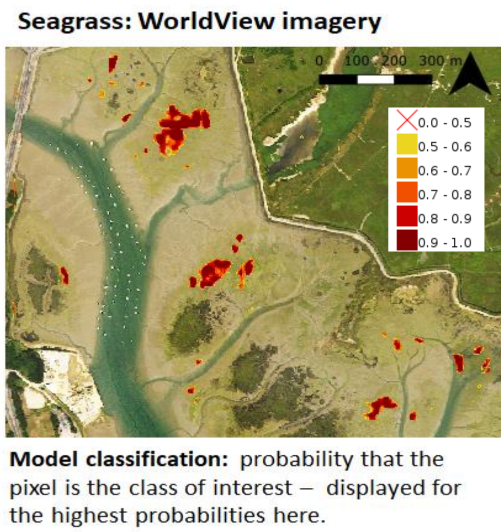


Figure 5. High-resolution seagrass map example.

The validation f-measure scores must be considered in the context of the limited data available for training, and thus a small subset used for validation. Consideration of the overlap of the probability maps with the ground truth data demonstrated that detection using this modelling approach for their detection is feasible.

As large datasets are required for deep learning models, the limited suitable ground truth data with corresponding satellite imagery that is cloud free and at low tide has placed limits on the robustness of the models produced. Seeking further data outside of the Solent is one way that the training dataset could be increased to improve the performance of the models developed. However, the focus here was on data for the Solent region as a case study.

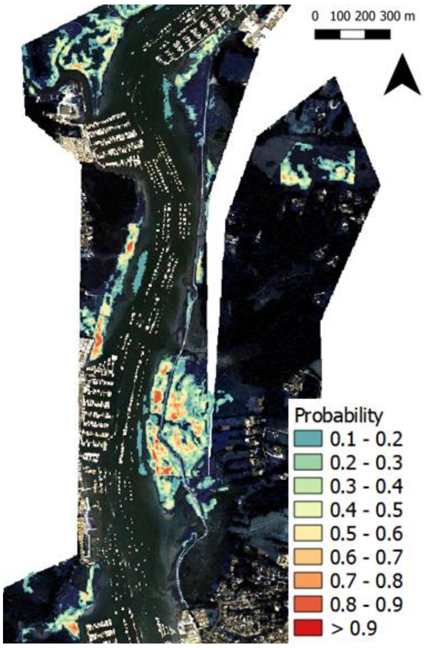


Figure 7. High-resolution algal mats map example for detection from WorldView imagery. Probability that the pixel is the class of interest – not displayed for the very lowest probabilities here.

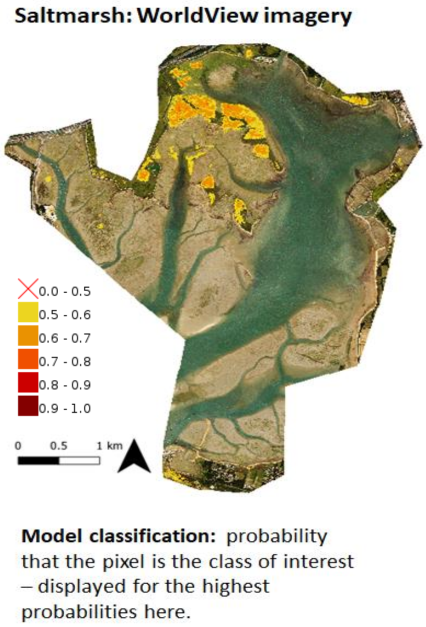


Figure 6. High-resolution saltmarsh map example.

Table 7 shows the model performance metrics for the detection of intertidal vegetation on Sentinel-2 imagery.

Table 7. Model performance metrics for algal mats, seagrass and saltmarsh (Random Forest model) on Sentinel-2 imagery.

Models training		Omission Error (percentage missed)	Commission Error (percentage classified)	Overall accuracy
Sentinel 2	Algal mats	40%	70%	80.90%
	Seagrass	98%	81%	
	Saltmarsh	43%	90%	

The modelled outputs demonstrate the feasibility of region-wide classification of the three classes when suitable satellite imagery is available. Sentinel 2 with a revisit time of 5 days offers the possibility of regular products and a Random forest model was trained and tested on a 20m Sentinel 2 image acquired in July 2020. The model was relatively successful but over classified pixels from all three classes and was very poor at detecting Seagrass accurately (over detection in general). Each dataset/source use different habitat code which might have resulted in some confusion in the model. The result does show the potential to use the data source in the future, and a more unified approach to data labelling would be one way to improve any future results, in addition of using a more advanced model for this kind of classification.

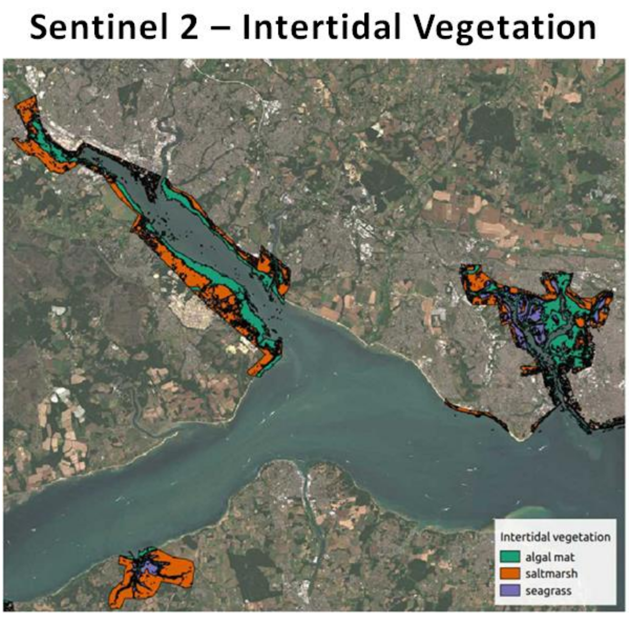


Figure 8. Low-resolution intertidal vegetation map example.

5. Evaluation Report Summary

5.1. Internal Evaluation

An internal evaluation of TEMITH outputs was undertaken to identify current model capabilities and limitations to inform further development. Modelled outputs were considered relative to training data, other in-situ datasets for sites used in training, or relative to known areas of sediment disturbance (for test images).

5.1.1. Intertidal vegetation models

ResU-Net detections:
***Algal mats* -** High confidence detections achieved at one site in areas of high density algal cover. The ability of the model to generally distinguish algal mats from the adjacent saltmarsh was demonstrated in certain locations. Model does not detect all algal cover at site where highest density is detected, with some detections on land, and overestimates algal cover at another site due to confusion with other cover classes.

Saltmarsh - One site exhibited high confidence detections in relation to training labels, with greatest overlap occurring in areas of 'mid-low' marsh, according to the EA saltmarsh zonation dataset. Limited detection of saltmarsh achieved and at low confidence at one site, including some detections on land. At second site with more successful detections showed some overestimation on the shore and detections on land, whereas other areas showed underestimations.

Seagrass - High confidence detections were achieved within the areas with training data labels for seagrass. Very limited training data used and training label areas were not detected in full. Other seagrass areas delineated by ground survey (not used in training) were not detected, possibly due to lower density.

Sentinel Random Forest model: Demonstrated the feasibility of region-wide classification of the three classes when suitable satellite imagery is available. The coverage by the three classes is currently overestimated, including saltmarsh detections on land, and minimal coverage indicated for other non-target classes.

Key considerations for further development: Consistent and complete detections of each class and distinctions from other vegetation and cover classes will require more training data, especially for seagrass which had the most limited input training dataset.

5.1.2. Sediment disturbance CNNs

Digging - UAV/aerial: Good detections achieved in most validation clips including broad, continuous areas of disturbance, discrete patches, and detection in areas with algal cover or interspersed with algae. General, though not perfect, distinction from mooring scars and dredging in validation clips. Validation clips indicated some incomplete digging detections and incorrect detections of other features. Tests in new images or areas indicated detection of some, but not all digging, and some difficulties to distinguish from other scarring types.

Digging - satellite: Validation clips showed detections were achieved in high confidence digging areas. Tidal water reduced detection of disturbance at one site that otherwise exhibited good overlap with the emerged high confidence digging areas, including broad areas of disturbance and smaller patches. Tests of the model in other satellite images showed the ability of the model to detect some, but not all of the digging in the known areas of disturbance. Lower confidence digging disturbance was mostly undetected by the model. While high confidence training data was used, it is of interest that the lower confidence features are reflected (at lower confidence) in the probability map.

Boats - UAV/aerial: Detections were achieved at empty moorings and with boats present, scars associated with different style moorings, partially submerged mooring features adjacent to the water's edge, continuous and discrete areas of disturbance, and distinction from digging disturbance was achieved. Tests at new locations demonstrated the ability to detect a range of boat scar types, though not always full detection of the scarring visible, and detections on land, including around boats on land, were noted in some cases. One test area included moorings of a different type than included in the training data and only one standing pool was detected in relation to these.

Boats - satellite: Validation clips with mooring scars demonstrated detection of empty moorings with only standing pools and full mooring scarring features, with and without boats present. In some cases, the model distinguished natural channels that entered the scarring feature. Tests highlighted the potential issue of boat context versus detection of sediment scarring (e.g. detections around boats on land). However, not all boats in the images are detected. Detection of keel drags was not consistent across validation clips, indicating a need for further training data.

Dredging - UAV/aerial: Validation clips and test images showed detection of both separate dredge tracks and broader areas of dredging disturbance. A test in a spiral dredging area in a new location showed partial detection of these scarring features. Clips with lower confidence dredging showed limited detection of these features, even though they were visible. It would be useful for these features to be detected in full at a low confidence for consideration by the end user. Although some areas are detected, not all dredging disturbance is detected in the test areas.

Dredging - satellite: The satellite validation clips indicated the model's ability to detect individual dredging scars. In test images, some potential dredge scars were being detected underwater. Tests in new images and areas showed some detection from heavily disturbed areas with overlapping scarring, but not in full. The model currently picks up other linear features (natural channels, keel drags, water ripples) as well as saltmarsh areas.

Key considerations for further development: More training data required representing a greater range of contexts/morphologies to improve model detection and ability to distinguish from other scarring types and non-disturbance classes. For boats, the potential detection of context versus scarring must be resolved. Detections of lower confidence features at a lower probability by the model is relevant in the context of understanding the persistence of scarring. The potential for detections underwater and reliability of these as evidence of disturbance where conditions allow should be considered.

5.2. Evaluation Workshop results

See section 2.3. for Evaluation workshop methods. The questionnaire was completed by 17 of 19 participants. Multiple potential uses for TEMITH output maps (assuming fit for purpose) were indicated by the respondents, with the majority to develop/inform management plan, use for condition assessment/monitoring, and provide advice.

5.2.1. Algal mats, seagrass, saltmarsh – WorldView

Uses for satellite-derived maps: Visualisation of extent, tracking changes over time, flagging areas to investigate in detail (enabling more efficient allocation of resources), prospecting of new seagrass beds, alerting stakeholders to poorer conditions for boating caused by algal mats, providing a powerful visual to inform and educate stakeholders, support Habitats Regulations Assessments and site evaluations by authorities.

Quality/suitability of current maps: None of the questionnaire responses indicated that the high resolution maps were 'not suitable', however the need to improve accuracy was indicated.

Algal mats - Noted overestimations and underestimations in the mapped outputs. Best detections at a location with large patches of high algal density and limited areas with other classes that make the mapping difficult. The high resolution imagery is aligned with what the EA currently use.

Seagrass - Limited specific feedback for seagrass indicated that more seagrass seemed visible than detected, potentially only picking up high density within patches and not distinguishing from macroalgae

Saltmarsh - Limited specific feedback for saltmarsh indicated detection at one site looked like the best fit of all of the mapping

Requirements/considerations for improved accuracy: Improvements for detection of range of densities (algal mats and seagrass); distinction from other classes potentially contributing to overestimation (e.g. *Salicornia* - a saltmarsh plant, microphytobenthos, and seagrass); detection of *Salicornia* (indicated as difficult to detect from aerial imagery); detection of overlapping vegetation types; and requirement for corresponding ground data for each image to support confidence in detections.

Uses if limitations in accuracy: Provide best available evidence where surveys on foot are lacking; additional supporting evidence, but not used solely as concrete evidence; support for high level condition assessment work; use for surveillance rather than monitoring; use to inform higher resolution habitat mapping.

5.2.2. Algal mats, seagrass, saltmarsh – Sentinel

Uses for Sentinel-derived maps: With the high frequency and accessibility, Sentinel maps could be useful for change detection, indicating areas to investigate in more detail.

Quality/suitability of Sentinel maps: For the responses that qualified suitability, a small majority indicated 'not suitable' for seagrass and saltmarsh and 'suitable if accuracy improved' for algal mats. There are current inaccuracies that were noted in the three-class modelled output, which included seagrass overestimations, detection of saltmarsh on land, majority coverage of the shore by only the three trained vegetation classes and with clear delineations. Sentinel was indicated as not suitable for smaller waterbodies and, for the Solent, the timing of Sentinel visit is poorly aligned with the low tide period of interest for assessments.

Requirements/considerations for improved accuracy: For high resolution satellite imagery there were expected issues of discrimination of different classes due to spectral resolution, which would be more pronounced for the lower resolution Sentinel imagery.

5.2.3. Sediment disturbance

Uses for EO-derived maps: Great value in the overview and context to the location and extent of sediment disturbance provided by the TEMITH maps. The ability to make temporal assessments, to consider the combination of activities using the TEMITH models, and combining the habitat models with the sediment disturbance models to examine relationships was of interest. Key uses included informing management and providing a visual to inform/educate stakeholders.

Quality/suitability of current maps: There was more uncertainty for the quality of the maps for satellite imagery relative to drone imagery. Suitability of the different imagery types may depend on the application, where higher accuracy or exactness may be required for some compared to others. For examining patterns of change, exactness may not be important, whereas determining the source of disturbance and summarising the level of impact at a given site may require greater accuracy. For mooring scar detection, a 2m resolution was indicated as useful, based on the size of the mooring scars. There was a comment regarding the potential for the boat model to be overfitting and interest in how the model performs in areas without ground data.

Requirements/considerations for improved accuracy: For the modelled outputs, it will be essential to know when the corresponding imagery was collected. There was a comment regarding the potential for the boat model to be overfitting and interest in how the model performs in areas without ground data. The satellite models were more limited in terms of training data and will require more imagery and labelling to improve, however the outputs showed that detection is feasible. For the sediment disturbance models for drone/aerial photography, it may not require a lot of samples from a new sensor/site to fine tune the existing models.

Uses if limitations in accuracy: Change detection; additional evidence (e.g. court appearance for bait digging); visuals for informing/educating.

Drone usage: Current access to drone imagery was limited among questionnaire respondents, however drone usage was indicated as likely to increase in the next 5 years by most. This warrants the inclusion of a drone imagery upload feature on the TEMITH platform and further development of the sediment disturbance models for detection from this type of imagery.

5.2.4. Frequency and cost

Frequency: For responses indicating frequency required, the majority indicated once a year for vegetation outputs, on-demand/regular for digging and shellfish dredging, and seasonally for boating. There was high uncertainty for the required frequencies for sediment disturbance outputs.

Previous payment for services: Ten of 17 respondents indicated payment for drone/satellite mapping services in the past. Cost formats (including for aerial photography/CASI, not just drone or satellite) were per km^2, per small MPA/waterbody, per area (e.g. adjacent estuaries covered in a single summer), and total for multiple sites.

Cost: Cost estimates shared by EVW participants for aerial survey/imagery and mapping processes indicate satellite as a cost-effective option for EO data of high spatial resolution if accessed via Deimos Space UK's agreements with commercial satellite providers. Key considerations for a willingness to pay for satellite imagery and services are what part of a bulk order cost (via agreements) and subsequent mapped products falls to individual end users, the frequency of suitable imagery and the ability to task satellites for the spring low tides of interest, and the suitability of the TEMITH maps for a given application (cost consideration relative to resolution and/or accuracy).

5.3. Evaluation Summary

The TEMITH outputs achieved have demonstrated the feasibility of detecting key intertidal features using deep learning and Random Forest models for detection from EO data. The internal evaluation and workshop feedback raised key considerations and User Requirements for further development. Options for additional sources of data and offers for further discussions were also raised. There are already current projects and applications to which the TEMITH services would be directly applicable, as well as potentially supporting ongoing assessments. Workshop participants expressed interest in seeing where TEMITH goes next and engagement with this key group of prospective end users should be maintained moving forward.

6. Communications

Communications in 2019 and 2020 have reached core groups of prospective end users from the Solent, the southeast of England, to the national level, as well as wider communications at international conferences. **Locally**, TEMITH was communicated to Solent stakeholders via the **Solent Forum** (participation in four meetings with formal and informal presentations of TEMITH; one newsletter article; and articles/mentions in three e-news articles). Key stakeholders in the wider **Southeast region of England** were reached via the Channel Coastal Observatory Southeast Regional Coastal Monitoring Programme newsletter (Dec 2019 issue) and through a formal presentation (virtually) at the Annual Partner's Meeting in Oct 2020. Communications with EO specialists at the **national-level** were also achieved, including a Jan 2020 presentation to the Defra Earth Observation Centre of Excellence Implementation Group,

Figure 9. Living Planet Symposium

which is a group set up to share knowledge to advance the use of EO in public sector environmental services. **International** dissemination was achieved through presentations/posters at a number of **conferences:** 2019 - Data Space Conference; ESA's Atlantic from Space workshop; Living Planet Symposium; 2020 - ESA Phi Week; abstract submitted to Estuaries and coastal seas in the Anthropocene – postponed. TEMITH was also communicated via the web and social media through the TEMITH webpage and continuous posts on Deimos Twitter and Instagram.

7. Conclusions

The TEMITH project has progressed from the proposed detection of **four pressures in the intertidal zone** and development of a platform to focus on the development of the **sediment disturbance and algal mats** (and associated) models and the collection of key user requirements for the platform. **Six sediment disturbance models** (CNNs) were developed to achieve detections of **three disturbance activities** (licensable and non-licensable) from drone imagery/aerial photography and from high resolution satellite imagery. **Feedback from end users** on intertidal vegetation **highlighted the relevance of seagrass and saltmarsh (habitats of conservation importance)**, for which data collection was of interest to be able to distinguish algal mats from other types of vegetation. Three separate models were developed for detection of algal mats, seagrass, and saltmarsh from high resolution satellite imagery (ResU-Net) and one model for their detection from Sentinel imagery (Random Forest). The completion of the October 2020 **Evaluation Workshop demonstrated the interest in the TEMITH services** and highlighted **direct applications for the services**, including current and upcoming projects and supporting regular ongoing assessments. Further model development to improve accuracy and broader applicability can build from the internal evaluation and key considerations raised by workshop participants who currently collect and use data on these features. In summary for the project:

<u>TEMITH achievements</u>

- Successful **interdisciplinary collaboration**
- Demonstrated feasibility of detecting key intertidal features from EO data using **deep learning and Random Forest** models
- User feedback – **TEMITH services relevant** with direct applications to current projects and ongoing assessments

<u>Next steps for end user uptake</u>

- Further model development to **improve accuracy** and broader applicability.
- **Temporal assessments** valuable; statistics (e.g. % change) as well as extent. Ability to resolve scarring age of interest.
- TEMITH **models in combination**; holistic overview of multiple activities and interactions with habitats; mixed vegetation.
- Ability to extract **suitable low tide** archived satellite imagery and/or task satellites for periods relevant to end users. Explore potential for reliable underwater detections to expand suitable imagery availability.
- Examine **cost-effectiveness** (access to high resolution imagery and maps via centralized resource; more efficient allocation of resources for targeted higher resolution investigations).

<u>Offers of support from workshop participants</u>

- Additional data sources indicated, offers for further discussions, potential funding for further work already identified.

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