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D2.4 Rapid Habitat Assessment with Remote Sensing

This is the 1.0 version of Rapid Habitat Assessment with Remote Sensing. This document is a deliverable of the AMBER project.

DISCLAIMER

Executive summary

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Fluvial remote sensing is a sub-discipline of remote sensing which has been researching the specific problems of river characteristic retrieval for the last two decades. The result is a significant body of research that now enables end-user scientists to use a range of data platforms and data sources in order to derive meaningful information about river channels. This report details the state-of-the-art in fluvial remote sensing with a specific focus on how it can be used for rapid and low-cost habitat assessment. The report considers the three main platforms likely to be used by AMBER stakeholders and scientists: drones, aircraft and satellites. The report focusses on the key physical parameters of channel belt vegetation, channel dimensions and bed material calibre. The application of remote sensing and preliminary results from some relevant AMBER case studies is also described. The main conclusion of the report is that low-cost options such as consumer grade drones combined with freely available, high quality, satellite data, notably from the Copernicus constellation developed and managed by the European Space Agency, constitute the best way forward for large scale and rapid habitat characterisation which have the potential to greatly reduce required labour costs and operate at much greater extents. The current patchwork of legislation regarding drone usage in the EU may delay this vision, but new legislation planned for 2019/Q1 should allow for standardised drone and satellite survey protocols across all EU member states to be implemented.

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1 INTRODUCTION AND FOUNDATION CONCEPTS

The remote sensing of ecological habitats has made considerable progress in recent decades and remote sensing is now recognised as a powerful tool capable of measuring detailed physical parameters that constitute physical habitat (Zlinszky *et al*., 2015). If we consider the specific area of lotic habitats, then a number of technical developments now enable an ever increasing range of physical habitat parameters to be rapidly characterised from remote sensing data (Gilvear *et al*., 2008; Legleiter *et al*., 2004; Marcus *et al*., 2003). Here we give a state of the art in fluvial remote sensing from the specific perspective of lotic habitat mapping and assessment. We begin with a brief discussion of remote sensing platforms and sensors. We then present a foundation framework, the 4 types of image resolutions (Carbonneau and Piégay, 2012a), that can be used to organise and conceptualise the potential application of a given remote sensing technology to a specific ecohydraulic problem. We proceed to give further details on the remote sensing methods commonly used to extract the key ecohydraulic variables of topography, water depth, bed material calibre and vegetation characteristics. We discuss the increasingly important role of modelling, more specifically, sediment transport modelling in the context of river basins affected by human impoundments.

1.1 Coupling modelling and remote sensing for habitat characterisation

The use of remote sensing for integrated instream habitat characterisation was incorporated into the habitat surveys model as a foundation for MesoHABSIM habitat simulation framework (Parasiewicz 2001, 2007a, b). The first high-resolution aerial photography taken from low flying aeroplanes provided digital background for annotation of observed habitat features in the field (Parasiewicz et al 2008 and 2010). It eventually evolved towards using unmanned drone aircraft to capture and pre-annotate large river habitat distribution RGB photos. The first such application of unmanned aerial vehicle (UAV) for this purpose took place in 2010 during Instream Flow Study on Niobrara River in Nebraska USA. It included surveys on 300m wide braided and sandy sections, where it was almost impossible to recognize hydromorphologic features from the ground because if their large size (Parasiewcz et al 2014). Due to the highly dynamic hydromorphologic nature of the Niobrara River, it was necessary to use very recent imagery, hence aerial photos were acquired one to five days before the start of the survey. The images were geo-referenced and mosaicked together then clipped for use on handheld computers. The Hydromorphological Units (HMU such as riffles and pools) in the site were pre-annotated based on their appearance using a laptop computer. The survey crew would then investigate each HMU to validate the annotation, collect information on cover and hydraulic conditions relevant to fish, and make any necessary changes to the HMU boundaries (**Figure1**). This technique became very relevant for the AMBER project, as it set the stage for developing similar protocols for mesohabitat data collection on large rivers for the purpose of dam introduced quantifying changes.

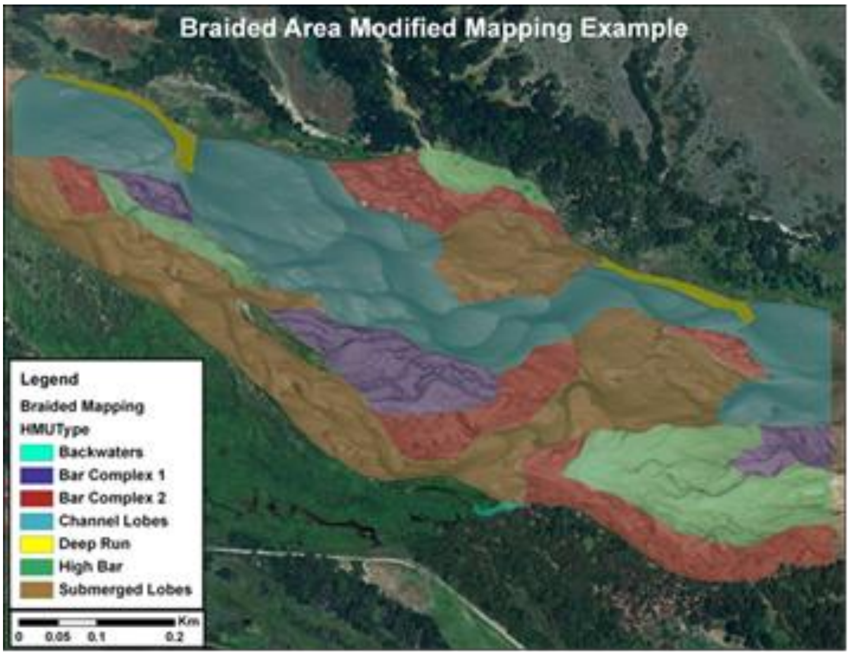

Figure 1: Habitat units pre-annotated on the aerial photos taken with UAV in 2010.

1.2 Platforms and sensors

Riverine environments and their associated habitats appear in a full spectrum of scales from 1st order streams of less than 1 meter in width to major rivers that have widths of a few kms and basins extending over millions of km^2 (Downing *et al*., 2012). Consequently, remote sensing platforms used to monitor and characterise rivers currently occupy the full range of technologies from low-altitude drones to satellites in both the government and private sector (**Figure 2**) (Carbonneau and Piégay, 2012b). Application extent and size of features required to be visible in the image are the typical determinants for platform selection. Whilst fixed limits are difficult to establish, satellite platforms are generally used for continental, national and regional scale work. Manned airborne platforms, both planes and helicopters, are typically used for regional to sub-regional work. Whilst small-scale deployments are possible for manned aircraft, financial and logistical considerations generally preclude their deployment for local surveys. These local surveys were traditionally done with ground-based intensive fieldwork approaches but, increasingly, drones are now becoming the platform of choice for local work. Moreover, the low-cost of drone operations is now starting to place considerable pressure on the manned airborne sector as small drone companies can successfully bid against full aircraft surveying. There are now drones, dubbed of 'prosumer' (i.e. professional consumer) level that can deliver outstanding image quality and fly over relatively long distances(see legal issues in section) for 20-30 minutes. These drones cost less than 5000 euros and can be safely operated by a team of two people.

Figure 2. The three main remote sensing platforms useable for habitat characterisation. Satellites (top left), here illustrated with the Sentinel-2 spacecraft from the EU Copernicus fleet; drones (bottom left), here illustrated as a Phantom 4 Pro by DJI Inc.; and manned airborne vehicles (right), here illustrated as a Robinson R-22 helicopter.

These low infrastructure and personnel costs are allowing small drone mapping firms to emerge and compete with the airborne sector in operations that are below 10km^2 in size. Consequently, we see drone technology as having a very high potential for AMBER stakeholders. Specifically, we see low-cost prosumer and consumer drones as being the most relevant in a context where most river management agencies cannot afford repeat surveys from manned airborne platforms or from expensive professional-grade drones costing above 10 000 euros and requiring much more experience to operate.

Sensors are distinct from remote sensing platforms. They are the actual imaging devices carried by the platforms. Mapping sensors come in a wide range of qualities and are capable of operating in a range of wavelengths ranging from 400 to 1000 µm (visible to infrared). The most common sensor currently in use is the familiar RGB colour camera. When used in a rigorous quantitative framework (see section below on photogrammetry), colour imagery can be interpreted and result in highly accurate and detailed maps. In this respect drones have been are increasingly recognised as an important development in habitat mapping. Given the low flying altitudes of drones, the resulting imagery is usually of very high resolution that Carbonneau *et al*. (2012) describe as 'hyperspatial' and define as images with spatial resolutions below 10 cm. This gives drone-based RGB camera sensors a very advanced feature recognition potential. Still in the realm of low-cost and accessible sensors, infrared cameras are increasingly available. The importance of infrared remote sensing is not new. The chlorophyll molecule reflects infrared light very strongly. Therefore, remote sensing of vegetation has long depended on infrared imagery and the earliest civilian remote sensing mission in the Landsat program carried the MSS (multispectral scanner) sensor designed to collect infrared as well as colour imagery. More recently, the Sentinel2 platform is equipped with a sensor with multiple bands in the infrared region and with spatial resolutions of 10 and 20 meters. In addition to low-cost sensors, high-end sensors are also available with improved spectral and radiometric resolutions.

1.3 The four types of image resolutions.

Carbonneau and Piégay (2012a) establish four types of image resolutions that can be used as a framework or a set of guidelines when considering the application of remote sensing to a specific problem in river sciences. These four resolutions are: spatial resolution, spectral resolution, radiometric resolution and temporal resolution.

1.3.1 Spatial resolution

Spatial resolution is the most familiar. Sometimes referred to as 'ground sampling distance' (GSD), this defines the spatial extent, usually square, of one image pixel. It is expressed in linear units. In the rare cases where the pixels are not square, the values are expressed as two dimensions (e.g. 5 m X 20 m). The spatial resolution of an image is not equal to the number of pixels in the image and its precise determination also depends on the geometry of the image acquisition scene (Carbonneau and Piégay 2012b; Carbonneau *et al*. 2012).

1.3.2 Spectral resolution

Spectral resolution refers to the bandwidth detected in the image generation (i.e. measurement) process. Imaging sensors (see below) capture a specific part of the electromagnetic (EM) spectrum and convert the detected radiance into image brightness values, expressed in the Digital Numbers (DN) that form the actual numeric values stored in each image pixel. The spectral resolution of the image therefore expresses the sensitivity of an image in terms of radiation wavelengths. It is expressed in linear units of wavelengths such as nm or µm. Spectral resolution information is often accompanied with specifications on which part of the EM spectrum is captured. For example, newly emerging 'hyperspectral' imaging sensors designed for drones typically have spectral resolutions of 5nm in the range of 450 nm to 950 nm. Furthermore, many satellites capture data with a spectral resolution that varies across the different satellite bands. For example, the Sentinel-2 satellite from the European Space Agency's (ESA) Copernicus program captures images with spectral resolutions of 15 nm, 20 nm, 35 nm 60 nm, 90 nm, 115 nm, and 180 nm. This design feature is meant to improve the satellites' ability to detect certain landscape features by using specific chemical features that are expressed as specific properties of the electromagnetic emission spectrum of the materials under consideration.

1.3.3 Radiometric resolution

Radiometric resolution refers to the storage format of the imaging products. Digital imagery must be stored in the binary format used in computer processing architecture. Each image pixel much be coded according to this binary structure. The fundamental unit is the binary bit which can only hold values of 0 or 1. A series of bits is called a byte. The amount of information that can be held in a byte is determined by the number of bits in the series. For example, 2-bit data can only encode four possible values (or states): 00, 01, 10 or 11. If we try to form an image with 2-bit pixel s*patial resolution* is the most familiar. Sometimes referred to as 'ground sampling distance' (GSD), this defines the spatial extent, usually square, of one image pixel. It is expressed in linear units. In the rare cases where the pixels are not square, the values are expressed as two dimensions (e.g. 5 m X 20 m). The spatial resolution of an image is not equal to the number of pixels in the image and its precise determination also depends on the geometry of the image acquisition scene (Carbonneau and Piégay, 2012b; Carbonneau *et al.*, 2012); there is a choice of four shades of grey, i.e. four brightness values. The colour imagery of our daily experience is composed of three bands each with a radiometric resolution of 8-bits. This means that each pixel in all of the bands in red, green and blue can hold 256 different brightness values. This type of 8-bit is extremely common in all types of airborne mapping. However, in the case of satellite remote sensing, the trend is now for 11 or 12-bit data. This improves the ability of satellite imagery to record subtle differences in brightness (Carbonneau and Piégay, 2012b).

1.3.4 Temporal Resolution

Temporal resolution obviously refers to the return period of repeated image acquisition. This is a simple yet important factor. Habitat monitoring requires repeat imagery at a return period that allows managers and scientists to detect any changes, either positive or negative. This is expressed in time units, usually days. Temporal resolution varies according to the sensors described below. Typically, satellite products useable for environmental monitoring have a return period of one to two weeks. For example, the Landsat series of satellites which provide a continuous record of the Earth's surface at spatial resolutions ranging from 60m (Landsat 1-5) to 15m (Panchromatic and of Landsat 7 and 8) have return periods of sixteen to eighteen days. The Sentinel-2 program now achieves a return period of five days (at 20 and 10 meters of spatial resolution) thanks to the operation of twin satellites. In terms of airborne remote sensing, whilst it is obviously possible to fly an aircraft over a given area on a nearly daily basis, cost and logistical constraints mean that, in practice, repeat airborne surveys only occur on a multi-annual basis, meaning an effective resolution of several years. Drones are currently the most reliable high temporal resolution platform. With their ease of deployment at minimal cost, the repeat acquisition of imagery is now very feasible. Obviously, this comes at the cost of study extent since drone platforms can only be expected to survey a few km^2 per day.

2 MAPPING RIVER HABITAT CHARACTERISTICS RELEVANT TO SCIENCE AND MANAGEMENT

2.1 Vegetation

Historically, vegetation monitoring has always been a fundamental part of remote sensing. The chlorophyll molecule has very specific reflectance properties in the infrared part of the EM spectrum. The first civilian remote sensing satellite, Landsat 1, was designed to acquire an image band suitable for chlorophyll detection thus starting a long tradition of vegetation monitoring in the remote sensing community. In the years since the launch of the Landsat program, the changing usage patterns of different remote sensing platforms (i.e. drones, manned aircraft and satellites) can perhaps foreshadow current and upcoming trends for fluvial sciences and management. In the case of vegetation, satellite remote sensing has always been a fundamental tool for any large scale investigation involving all aspects of vegetation change e.g. (Hislop *et al*., 2018; Shoshany, 2000; Zarco-Tejada *et al*., 2018). However, in the last 15 years, the rapid development of drone technology has had a major impact on vegetation monitoring for both academic and commercial purposes. Papers reporting the use of drones as an airborne platform to acquire remotely sensed data now dominate the field for small scale applications e.g. (Flynn and Chapra, 2014; Husson Eva *et al*., 2013; Laliberte *et al*., 2010). Whilst there have been some efforts to use manned aircraft (e.g. Graham, 1993), usage of this platform has all but disappeared in vegetation studies. We are therefore left with a situation where remote sensing data for vegetation monitoring is acquired at local scales from drones and at global scales from satellites. It would appear that fluvial sciences are following a similar pattern with manned aircraft usage also on the decline.

2.2 Channel and catchment topography

Topography is generally considered as the primary descriptor for physical processes at the earth surface. In terms of the fluvial environment, topography influences river slope which in turn controls sediment transport and a range of habitat features. Consequently, topographic data is often the primary element of river network analysis (Bizzi *et al*., 2016). Topography data is generally organised according to scales. At national and regional scales, satellite data tends to be the only realistic option. Whilst there are commercial options, their cost can be quite high and their usage in the course of AMBER and uptake by AMBER stakeholders is not likely. Most member states will have their own datasets with specific spatial resolutions. In their absence, the NASA dataset collected by the Shuttle Radar Topography Mission (SRTM) remains a valuable resource (Farr *et al*., 2007**). Figure 3** shows the topography of Glen Garry, Scotland, (an AMBER case study) as taken by the SRTM near-global elevation model.

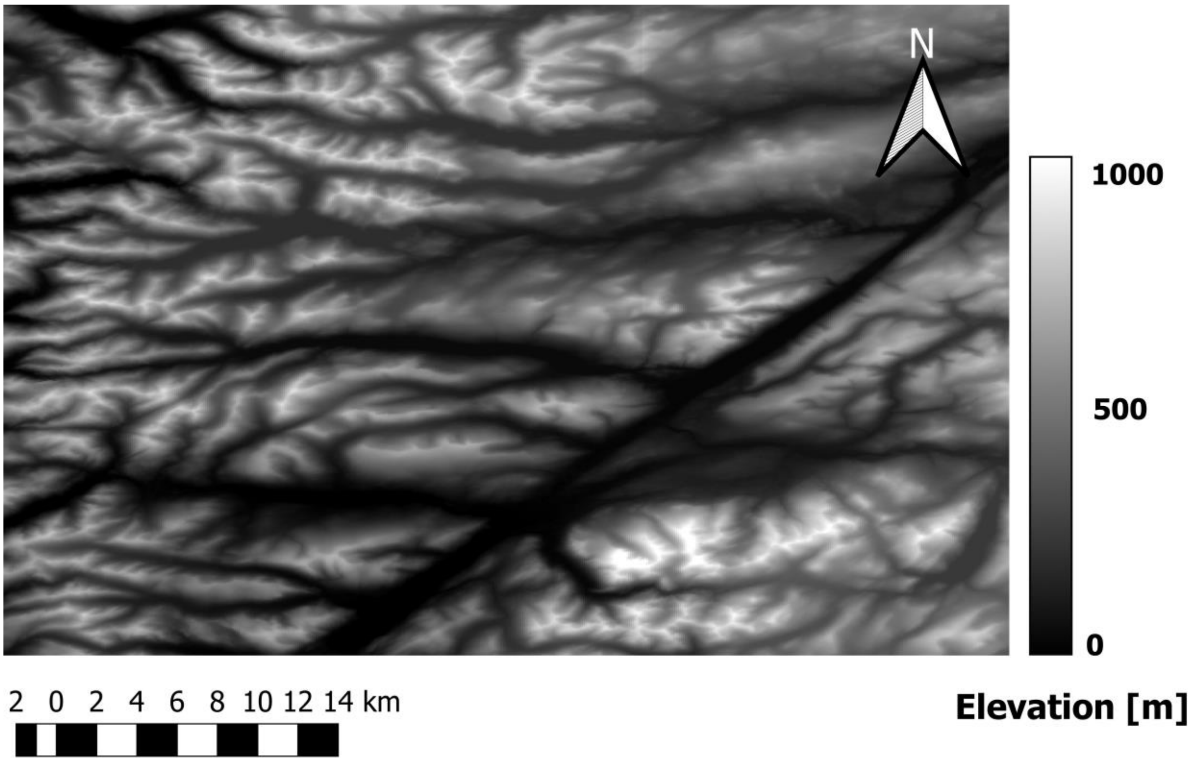

Figure 3. Topography of Glen Garry, Scotland, used as a case study in WP4 of AMBER.

At smaller scales, topography production and mapping relies on airborne sensors (airplanes, helicopters and drones). Since the development of aviation and photography, aerial images have played an increasingly important role in terrain mapping. A crucial technology in this process has been photogrammetry (Wolf *et al*., 2013). Photogrammetry is the methodology whereby a series of 2D images can be converted into a 3D landscape. When used in a geographic context, the process also results in the spatial location (i.e. geo-referencing) of each 2D image. The photogrammetric process also allows for the orthorectification process which removes scale variations within each image that result from differences in elevation in the landscape (Morgan and Falkner, 2001; Wolf *et al*., 2013). In its initial stages of development, photogrammetry was a very labour-intensive process e.g. (Carbonneau *et al*., 2003). Fortunately, recent developments have now delivered a new photogrammetric workflow called Structure from Motion (SfM) which has delivered a true step change in our ability to transform images into mapping products (Fonstad *et al*., 2013; Westoby *et al*., 2012). SfM-photogrammetry uses innovations in artificial vision emerging from computer sciences in order to automate the most labour intensive step in the photogrammetric process: that of locating each image in 3D space (Fonstad *et al*., 2013). This results in an accelerated photogrammetric process with a level of automation that makes it suitable to a wider audience with a much lower level of expected technical expertise. The development of SfM has proven to be critical to the co-evolving development of drone-based mapping. SfM technology has allowed for the large and relatively unstructured image sets acquired by drones to be processed and easily transformed into 3D mapping products with remarkably little effort. **Figure 4** shows an example from Gayle beck in the Ribble catchment in Yorkshire, UK. Part A shows a 3D model produced from drone imagery. Part B shows an orthoimage prepared with the open-source GIS interface QGIS and thus transformed into a basic map. In the next section, we will provide further discussion on the extraction of additional parameters that are relevant to lotic habitats. One key element of the data presented in **Figure 4** is the removal of the use of a field data collection protocol called 'Direct

Georeferencing' (DG). In classic photogrammetry, the user must deploy ground targets that must be surveyed to a very high accuracy with expensive survey equipment. The required equipment, e.g. Real Time Kinematic GPS, Robotic Total stations or Terrestrial Laser scanners, costs in the area of 10 000 – 40 000 euros. This requirement for expensive survey equipment is therefore somewhat at odds with the new developments in drone technology. Users that want to implement drone mapping therefore find themselves in an odd situation where the cost of the imaging platform is an order of magnitude below the cost of required survey equipment (Carbonneau and Dietrich, 2017). DG was specifically developed to obviate the need for ground-based surveys (Carbonneau and Dietrich, 2017; James *et al*., 2017; Turner *et al*., 2014). With this approach, 2D and 3D mapping products can be produced solely on the basis of the positional information recorded by the drone or aircraft. The resulting 2D and 3D products have full spatial and scalar information and are suited to all mapping applications. This has the obvious benefit of reducing capital equipment costs but also of reducing the requirement for direct site access. DG is currently an active field of research in geography. Readers should note that at the moment, the errors associated to DG mapping products do impose certain limitations on the fields of application (Carbonneau and Dietrich, 2017). Typically, the expected errors from DG are a precision better than a half-meter for elevations and better than 10 meters for XY location. Object scales are correct to within 1%. Whilst these parameters tend to limit the value of DG products in some disciplines such as geohazards monitoring, they are well suited to habitat mapping needs such as those of the AMBER project.

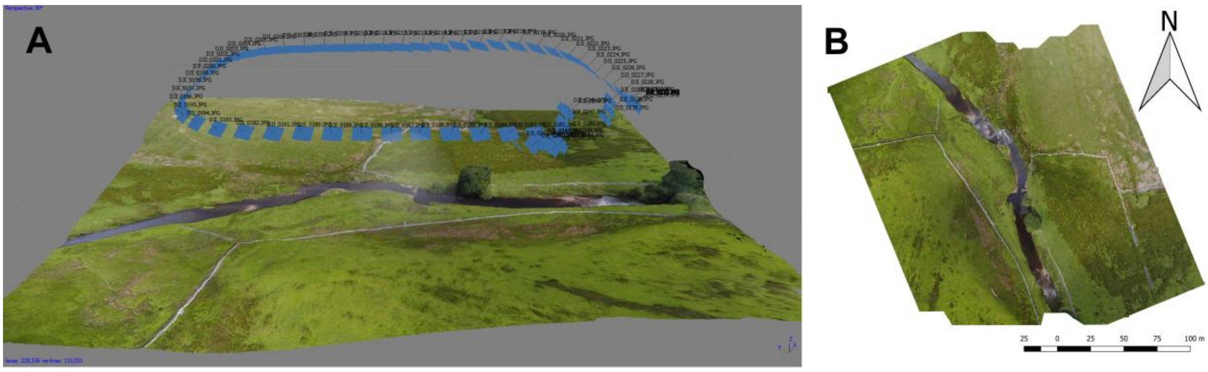

Figure 4. A) 3D scene around Selside weir on Gayle Beck in North England. The blue rectangles represent the position of the images acquired by the drone. The ground below is composed of over 2 million individual points that give the XYZ locations of the topography as well as the associated colour. B) Orthorectified image and map produced from the data in prat A).

2.3 Channel Width

Channel width is a well-established, basic, descriptor of habitats and it has been shown to be a reliable metric for many ecohydraulic processes (Beechie and Sibley, 1997; Newson and Newson, 2000). In most cases, it is the least problematic habitat parameter to characterise from aerial mapping. In the case of large rivers with widths in excess of ≈50 meters, freely available satellite data delivered by government agencies such as NASA and ESA are well suited to direct width determination of the channel. For example, 3 of the 12 image bands collected by the Sentinel-2 mission operated by ESA have a spatial resolution of 10 meters. Therefore Sentinel-2 imagery is well suited to width determination for rivers with a minimal width in the 30-50 meter range. The task of measuring river widths often involves an interpretative task whereby a human operator must visually determine the boundaries of the river. This could be time consuming for repeated measurements. However, the visual interpretation task of identifying the river in an image can be automated via the process of image classification (Snelder and Biggs, 2007; Thomson, 1998). Some authors have then built on this approach in order to fully automate the width measurement process and produce global-scale data sets for river dimensions (Allen and Pavelsky, 2015; Pavelsky and Smith, 2008). At smaller scales, airborne remote sensing is well suited to the reach scale extraction of channel width. Carbonneau *et al*. (2012) have demonstrated how the use of airborne imagery acquired from a manned plane could be used to automatically extract channel width for every 5 meter step in the downstream direction of the River Tromie in Scotland. Similarly, with the use of SfM-photogrammetry, drone imagery can easily be transformed into rigorous 2D maps useful for channel width determination (**Figure 4**) (Woodget *et al*., 2017).

2.4 Depth

The retrieval of water depth from remotely sensed imagery has a long track record of research. Whilst there are some methods that use LiDAR technology e.g. (Bailly *et al*., 2012), these methods remain costly and unlikely to be deployed in the course of the AMBER project. Therefore, here we focus on depth retrieval methods that rely on remotely sensed optical imagery. Lyzenga (1981) pioneered early work on water depth retrieval from imagery. Using the Beer-Lambert law that describes the diffusion of light through a medium, Lyzenga (1981) demonstrated that an image scene could be calibrated to produce a predictive relationship allowing for extensive water depth measurements. This general principle has been applied to satellite data (Dekker *et al*., 2011; Pacheco *et al*., 2015), manned airborne data (Bergeron and Carbonneau, 2012; Carbonneau *et al*., 2006; Winterbottom and Gilvear, 1997). Another possible approach is the use of photogrammetry to assess the position of the river bed in the cases where the river is shallow and the bottom is visible. In such cases, one problem which must be solved is that of the refraction effect caused by the air/water interface. This topic has been well researched and workflows now exist that can derive the topography of a submerged river bed from manned airborne imagery (Feurer *et al*., 2008; Westaway *et al*., 2001) as well as drone imagery (Dietrich, 2017; Woodget *et al*., 2015). However, readers should note that water depth retrieval has well established limitations. In simple terms, the submerged bed must be partially visible in order to establish its depth. In cases where the water is too murky and laden with suspended material, depth retrieval is not possible. Legleiter *et al*. (2004) examined this issue in more detail and established advanced criteria for successful bathymetry retrieval. Notably, these authors found that the radiometric resolution is a key parameter. However, in the case of small streams with clear flowing water, bathymetric SfM from a drone platform is a very cost effective alternative to manual depth soundings.

2.5 Grain size

Grain size is a key descriptor of many hydraulic processes (Ferguson *et al*., 1996; Rice and Church, 1998). Furthermore, it has long been recognised as a key habitat preference for salmonids (Armstrong *et al*., 2003; Cunjak, 1988; Rimmer *et al*., 1983) and lamprey (Beamish and Jebbink, 1994; Malmqvist, 1980). From a measurement perspective, grain size is challenging and highly labour intensive to measure in the full river continuum. Consequently, remotely sensed measurements of riverbed material grain size have been an active focus of research for the past 15 years. Carbonneau *et al*. (2004) made the first demonstration that grain size mapping was possible from airborne imagery. Using imagery with a spatial resolution of 3cm, these authors were able to demonstrate that specific properties of gravel bar imagery were directly correlated to the particle size of the material that composed this gravel bar. This in turn allows for the calibration of the image and the development of predictive relationships which can be applied to large image data sets and thus extract continuous grain size information at large scales. This same principle was then applied by Carbonneau *et al*. (2005) to the submerged part of the river and it was demonstrated that submerged grainsize prediction was also feasible. Further developments in the field then established other image properties that are useable for grain size mapping such as autocorrelation (Rubin, 2004) and wavelet transforms (Buscombe *et al*., 2010; Buscombe and Masselink, 2009). A body of research therefore emerged capable of measuring grain size for the entire length of small or medium rivers by using manned airborne imagery. However, manned airborne remote sensing has proven to be an often costly option the deployment of which presents significant logistical challenges. In response, drones have now become the *de facto* platform used by most fluvial scientists and managers owing to their extremely low cost and ease of deployment. Whilst drones are much easier to deploy, drone flight is carried out at much lower altitudes and is less controlled than that of full size aircraft and therefore grain size mapping algorithms developed for the manned airborne sector are not ideally suited and must be transferred with caution. Woodget *et al*. (2017) examined the issue and proposed new approaches that successfully adapt grain size mapping algorithms used for manned airborne imagery to the specific characteristics of drone imagery. More recently, members of AMBER demonstrated an innovative use of drones in the field of grain size measurement (Carbonneau *et al*., 2018). Dubbed 'Robotic Photosieving', this new approach uses low-cost drones in near ground flights in order to get highly detailed images of river gravels (**Figure 5**).

Figure 5. Schematic illustration of the Robotic Photosieving process. The drone is programmed to fly very low near the gravel bar in order to acquire highly detailed images of gravels that can be automatically sized. Collision avoidance systems and pilot control assure public safety.

The mm-scale spatial resolution of these images allows for individual stones to be detected in each image. The method further innovates by using SfM-photogrammetry and Direct Georeferencing to calculate image scale and thus the entire method does not require any form of ground validation or ground measurements. The drone is transformed into a fieldwork robot and the labour-intensive task of grain size measurement is automated. **Figure 6** compares results from Robotic photosieving with an image scale determined from SfM-photogrametry to standard photosieving where scale is determined by a user who performs an on-screen measurement of an object with known scale. The distributions in **Figure 6** are statistically identical.

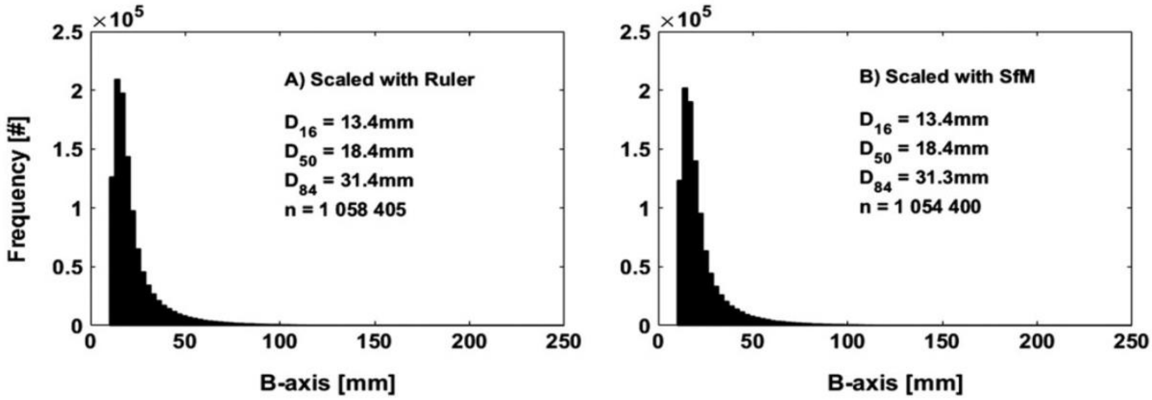

Figure 6. Statistical validation of Robotic photosieving. This figure shows identical distributions when a dataset is processed with the robotic photosieving approach compared to the traditional approach where a human user must measure a scale in each image in order to determine image scale (from Carbonneau et al., 2018).

2.6 Coupling modelling and remote sensing for habitat characterisation

The increasing availability of different source of remote sensing (RS) data supported by emerging new technologies is also transforming our capacity to model environmental and physical processes. Modelling is playing an increasingly important role in all fields of environmental science because of its ability to project our understanding of a given environmental process at longer time scales and larger physical scales. If we take the AMBER project as an example, it is clear that there is a high density of barriers on EU rivers that affect a very high percentage of EU territory (Belletti *et al*., 2017; Schiermeier, 2018). After the application of mitigation and removal measures applied to the type of small dams and barriers which predominantly affect EU rivers, the channels and ecosystems are expected to take several years, if not decades, to fully restore themselves to a pre-impoundment status. Having tools that can predict the evolution of channels beyond the lifetime of the AMBER project is therefore crucially important. Focusing our attention on large scale modelling opportunities, over the last years the availability of high and medium resolution topographic data have allowed assessments of landscape features at the river network scale or even global scale that were not possible in the past (Passalacqua *et al*., 2015, 2012; Pavelsky and Smith, 2008; Schmitt *et al*., 2014,; Yamazaki Dai *et al*., 2014). The integration of global scale topography from SRTM DEM with large scale hydrological archives have opened to the opportunity to develop continental and global scale hydrological models to assess flood hazard and droughts (Dankers and Feyen, 2009; Forzieri *et al*., 2014; Van Der Knijff *et al*., 2010). Adding to these datasets information from optical satellites have allowed to characterize riparian forest at pan-European scale and to study its capacity as buffer zones and green arteries (Weissteiner *et al*., 2016, 2014). In this context, the analysis of how connectivity governs geomorphological and biological processes through mass and energy transfer within landscapes is attracting growing research interest (Bracken *et al*., 2015; Fryirs, 2013; Wohl *et al*., 2018). Coupling high resolution topography to extract landscape and river features with hydrological and biological information has advanced our understanding of water, solid, and solute transport through deltaic networks (Hiatt Matthew *et al*., 2018; Sendrowski *et al*., 2018). Drivers of sediment transport, such as stream power, have been calculated through entire river networks integrating Digital Elevation Model (DEM), hydrological, geological and river geomorphic information available at basin scale to derive different metrics of sediment connectivity (Bizzi and Lerner, 2015; Czuba and Foufoula-Georgiou, 2014; Heckmann *et al*., 2014; Parker *et al*., 2015; Yochum *et al*., 2017).

Of particular relevance to AMBER's work on physical habitats is the CAtchment Sediment Connectivity And DElivery (CASCADE) modeling framework (Schmitt *et al*., 2017, 2014). CASCADE simulates provenance, transport and deposition of sediment across the entire river network. CASCADE describes the movement of sediment from many individual sediment sources (each with a characteristic grain size and supply rate) in a river network as a separate cascading process (**Figure 7).** CASCADE considers rates of transport separately for many sediment cascades (rather than bulk rates for each reach). This cascade-specific approach enabled quantifying the rates with which specific sediment sources connect to downstream reaches, and how the connectivity between many sediment sources and downstream reaches leads to an emerging pattern of network sediment connectivity. CASCADE provides a static picture of source to sink relationships given a specific network morphology and a hydrological scenario. It describes present connectivity features of a river network. It is not a dynamic model which simulates river channel morphological changes. For this reason, its computational time is fast and can be applied on large basins worldwide with moderate effort.

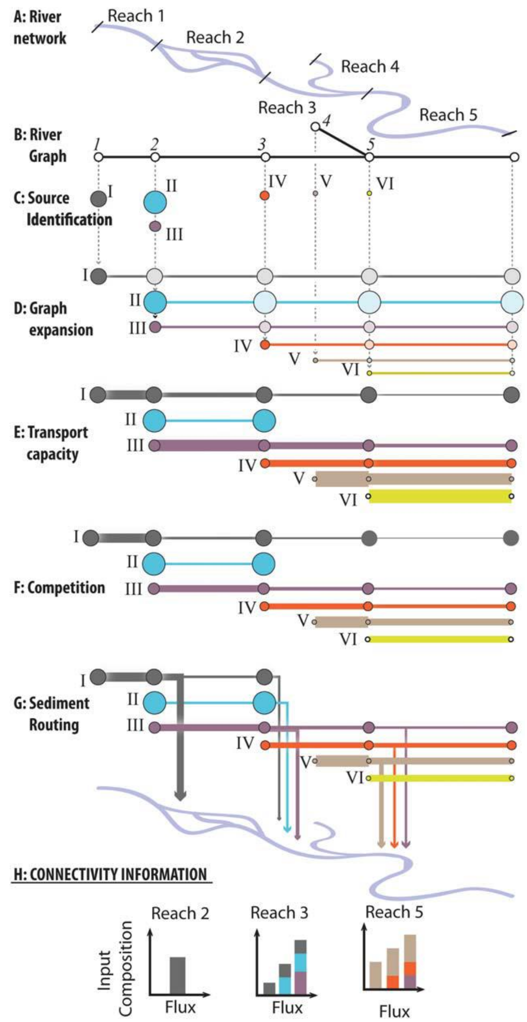

Figure 7. Key concepts and steps behind the CASCADE modelling framework (taken from Schmitt et al., 2016). (a and b) Original river network and graph representation. (c) Identifying source locations and grain sizes. (d) Graph expansion. (e) Transport capacity scaling, line width indicates transport capacity. (f) Competition reduces the original transport capacity (compare linewidth in **Figures 7e and 7f**). (g) Cascade specific, edge-to-edge sediment routing discriminates cascade sediment fluxes. (h) Edges receive fluxes from multiple cascades, defining sediment flux, provenance, and sorting; and thereby connectivity of an edge.

The CASCADE model is particularly relevant in the context of the AMBER project since it enables a quantitative, spatially explicit analysis of network sediment connectivity with potential applications in both river science and management. For instance, it allows us to evaluate the alteration of sediment connectivity caused by different configurations of dam portfolios (e.g., different configurations of dam removal sittings) within a basin. CASCADE developers have studied the cumulative effects of constructed and planned dams on the Mekong Delta (Schmitt *et al*., 2018). They have found unexplored solutions where economic and environmental objectives can both be satisfied. The study concluded that the current site-by-site planning for hydropower should be replaced by a coordinated, trans-national, network-scale planning of hydropower portfolios in order to avoid economically and ecologically sub-optimal results. An interesting avenue of research for AMBER is the coupling of recent drone technology to this network model. In this context, low-cost UAVs could provide novel opportunities to calibrate and validate network-scale models such as CASCADE. The progress described above indicates that drones could be a powerful sampling tool for river properties such as channel width and grain size thus allowing better tuned model outputs. Such a monitoring and modelling framework offers a cost-effective opportunity (affordable to any water related institution in Europe) to the understanding of sediment dynamics in fluvial networks.

3 REMOTE SENSING IN THE AMBER WORK PACKAGE 4 CASE STUDIES

3.1 Context and Rationale.

The AMBER partnership in general along with the specific case studies in work package 4 operates in the wide range of conditions present in European rivers. These vary from very small streams, such as Gayle beck in England, that are less than 10 meters in width and 1 meter in depth to major navigation channels, such as the Vistula River in Poland, which are several hundred meters wide and have a sufficient depth for major cargo vessels. The barriers present on these rivers vary accordingly and can therefore have heights that are below 1 meter to several 10s of meters. Management, removal and/or mitigation measures for existing barriers are also extremely varied and cannot be grouped into well-defined categories. Indeed, some member states, such as Poland, are actively pursuing barrier construction while others, such as Denmark, are in a phase of barrier removal. In parallel, the availability of remote sensing data is not standardised within the union. Whilst there is a uniform availability of space-borne products such as those from the EU Copernicus constellations of satellites (e.g. Sentinel-1 and Sentinel-2), there is no uniformity in the availability of remote sensing products acquired from airborne platforms (airplanes, helicopters and drones). This is largely due to different funding priorities for the acquisition of airborne data covering the national territory of each member state. Furthermore, the lack of EU-wide drone regulations (see section4 for details) means that some countries now allow the use of drones for low-cost and effective monitoring while others have banned this option completely. Consequently, the use of remote sensing technology as a primary data collection procedure use to quantify and/or qualify basic physical habitat variables in rivers and streams varies significantly across the AMBER consortium.

In addition, several scientific challenges have become apparent during the first 18-months of work in the partnership. Preliminary results from Work Package 1 (WP1) have clearly demonstrated that EU barriers are impounded by an average of one barrier for every two km of river length (Belletti *et al.*, 2017). Furthermore, WP1 also found that the majority of these barriers are small and have a height below two meters. It therefore becomes clear that European rivers are currently in a steady state of very low connectivity. The current regimes of sediment transport downstream and biota migration in river channels are adapted/regulated by the current number of impoundments. As part of the core mandate of AMBER, the project seeks to develop an understanding of the responses of impounded catchments following complete barrier removal or at least, improved mitigation and connectivity restoration measures. Furthermore, whilst the removal of small barriers is rapidly gaining favour across EU member states, there are no documented examples of large scale barrier removals. The future evolution of river catchments within the EU therefore seems to be predicated on the effects of complete removal for small barriers, and mitigation measures for larger barriers. This poses a significant scientific challenge in terms of temporal response scales. From the perspective of habitat monitoring, the understanding of the new steady state reached by river catchments that have benefited from small barrier removal will require long term monitoring that will exceed the lifetime of the project. Added to this complication is the exact removal schedule; within the EU, rates of dam removal vary widely and the removal of a specific barrier can be hard to predict, especially when funding sources are not clear. As a result, many barriers are in a state of awaiting removal, the end point of which is uncertain. This uncertainty makes scientific investigations of channel status pre and post removal difficult. Here we present four AMBER case studies where remote sensing is playing a role in the assessment of barrier impacts.

3.2 Work Package 4 Case Studies

3.2.1 River Vjosa: Integration of remote sensing to modelling via the CASCADE model

The development of CASCADE, and similar network-scale model frameworks, have been fostered by current availability of large-scale RS data. The first step in the implementation of CASCADE is the calculation of the transport capacity for each reach of the entire river network (see **Figure 8**). To do so, we need to derive a river network from a DEM and segment it in geomorphological homogeneous reach. One crucial function of CASCADE is the calculation of the river transport capacity. For this task the user has to provide information on type and supply of sediment (e.g., supply-limited or not) along each reach of the network. This allows us to examine multiple scenarios of dam construction or removal and then actually trace back the likely sources of sediment. The model even allows for a direct estimation of D_{50} (the median diameter) which can then be fed into habitat prediction models or compared to known preferences of key species e.g. (Cunjak, 1988). In **Figure 8**, we report preliminary results on the Vjosa case study in Albania. Whilst not yet a part of the Union, Albania is currently on the track for admission. This case study is a good example of a situation where drone operations are not currently allowed in Albanian airspace. Therefore, this application of the CASCADE model relies solely on orbital remote sensing data acquired from satellites. In this WP4 case study, a sensitive analysis on alternative supplies of sediment in the upper Vjosa basin has been carried out with a view to the potential impacts of a planned and intensive dam construction program. The river network is coloured based on average D_{50} calculated amongst all the simulations, boxplots report the range of simulated D_{50} for four specific reaches where field data are available, and the green line on the boxplots show the observed D_{50} in the field. Connectivity patterns generated by CASCADE are the results of the interactions of all the supplied cascades and their routing through the network driven by available transport capacity. For this reason, if CASCADE outputs match few scattered observations in a different strategic reach of the network characterized by different connectivity features, such as in **Figure 8,** it is an important validation that the representation of sediment transport phenomena at the network scale is properly represented. In the future development of this case study, the remote sensing data coupled to the CASCADE model will be used to propose more viable dam location sites that will mitigate the impact of these new barriers on the ecology and hydrology of the Vjosa basin.

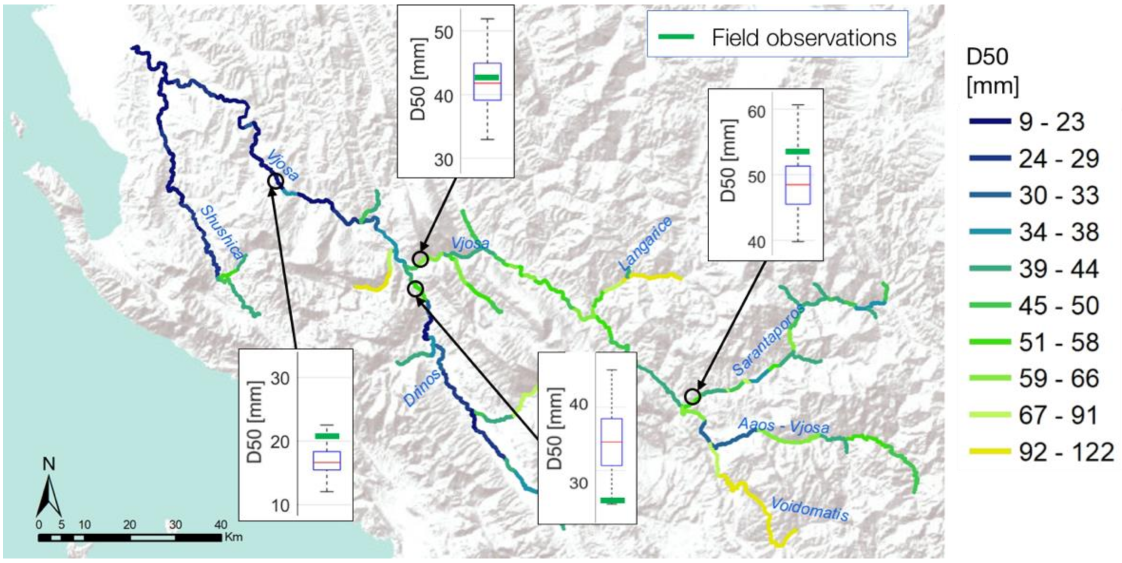

Figure 8. D50 simulated by CASCADE model simulations on the VJOSA River: coloured lines in the map show the average D50 derived by the simulation of a range of scenarios of supplies defined by expert opinions; boxplots report the range of D50 of the simulated scenarios of supplies for four selected reaches where field data are available, and the green lines on the boxplots show the observed D50 in the field.

3.2.2 Low-Energy systems, Denmark and the UK

The North West of Europe has a large number of low elevation watersheds that are generally characterised by gentle topography with sources below 1500 m Above Sea Level (ASL) and small catchment areas. These regions are heavily impacted by barriers, very often small barriers as found by Belletti *et al*. (2017). In many cases, there are encouraging efforts and successful examples of barrier removals. For example, there is currently an active dam removal plan for the River Eamont. This is a small and shallow gravel bed river flowing from the hills of the Peak District. The water is generally clear, although slightly laden with dissolved organic carbon that darkens the water. This river is therefore a good candidate for the parameter characterisation methods described above, especially those based on drone imagery. This river is currently affected by four impoundments. Dam removal operations began at the downstream end of these impoundments with Carleton weir just outside the town of Penrith in June 2016. The site is being monitored by AMBER partners at Durham University. **Figure 9** shows a before/after scene created with 3D rendering of high resolution drone data illustrating the removal of Carleton weir. The scene on the left was gathered in March 2016, before the official start of the AMBER project and the scene on the right was acquired in June 2017. It should be noted that the major apparent change, the erosion and apparent clipping of the gravel bar downstream of the weir emplacement, was in fact a manmade feature occurring during the weir removal process and intended to facilitate flow of water after the bank removal. It should also be noted that another important barrier is in place just 1km upstream and therefore any changes in sedimentary dynamics as well as in fish populations are now likely now inhibited by the presence of the upstream impoundments. Furthermore, the small scale of the system would suggest that the re-adjustment of this system will occur on multi-year, perhaps even decadal timescales. The determination of this response time is in itself an important research question. Given that the likely response time will in fact be longer than the AMBER project, Durham University work will apply the CASCADE modelling framework in order to address this question with a modelling approach that will allow AMBER to explore river response over long timescales. The Eamont catchment will be one of 2 main study sites for this effort. This study will be focussed on determining time scales at which the sediment transport in a river adjusts to barrier removal. The Eamont is a salmon river, and therefore the nature and calibre of the sediment is an important driver of physical habitat suitability (Armstrong *et al*., 2003). This work will therefore move to improving the performance of CASCADE by using drone-based grain size mapping to provide quantitative data in order to improve the calibration and validation of CASCADE outputs.

Figure 9. Barrier removal of Carleton weir on the River Eamont in Northwest England. Left: initial situation with an overtopping weir of ca. 1 meter in height. Right: 12-month post removal situation. The apparent bank erosion of the gravel bar downstream of the barrier is man-made and was dug out during the removal process.

Denmark is also engaged in an active phase of barrier removal. However, from a remote sensing perspective, the situation is different than the UK scenario. Barrier removal in Denmark is currently focused on small barriers that may obstruct fish migration. The affected channels are extremely narrow (less than 1 meter) and very dark. This renders them unsuitable for satellite and airborne remote sensing analysis and even low altitude drone-based data has limited value. **Figure 10** shows Øster Ørts Dambrug (barrier) on the River Flynder in Denmark. This is a much smaller channel, with much finer bed material, and an absence of classic fluvial forms (bars, meanders, riffles and pools). In such cases, drones provide a good platform to document the actual barrier itself but the possibilities for retrieving habitat properties other than channel width are very limited. AMBER partners in Denmark are nevertheless acquiring repeated drone imagery for recording purposes and as the basis for the production of outreach material illustrating and documenting the removal process.

Figure 10. Orthophotograph of Øster Ørts Dambrug (barrier) on the River Flynder in Denmark

3.2.3 Garry Catchment and loch Quoich dam

Remote sensing is also being deployed in the Garry catchment case study for WP4. This catchment is affected by Loch Quoich dam which is a 4m dam with a small hydropower facility of 18.5Mw. The dam creates an impounded lake with an area of 17km^2. The catchment also has a southern branch, the River Kingie that remains free flowing (**Figure 11**). The site therefore offers an interesting twinned configuration suitable for a comparative experiment. Here Durham University will once again apply the CASCADE model in order to better understand the potential changes in sediment delivery caused by the construction of Quoich dam. Furthermore, Durham University will support AMBER colleagues from the University of the Highlands and Islands in an experiment investigating the possible usages of drone data in the selection of sites used for eDNA sampling. The objective here is to combine depth mapping and sediment size measurements to identify the most suitable locations for the eDNA water sample to take place. Additionally, if there is a requirement to sample from deeper waters, a drone-mounted sampling device could be envisioned.

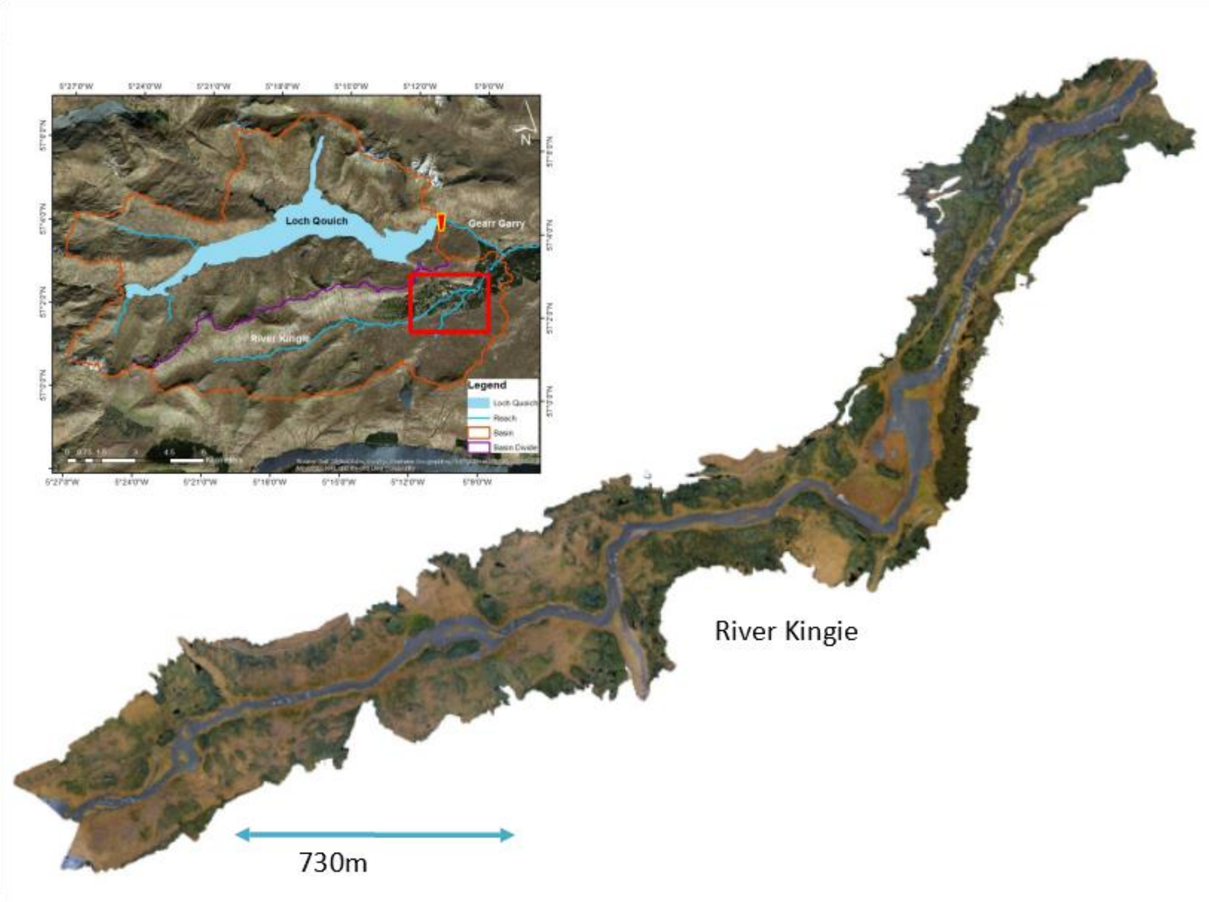

Figure 11. Preliminary survey from the Kingie river conducted in July 2017.

3.2.4 River Vistula, Poland

The River Vistula is the longest river in Poland. It is a major European river with a catchment area of 194 424 km2 which also straddles Belarus, Ukraine and Slovakia. It provides a navigation access to the Baltic Sea and thus is an important shipping lane with access to inner territories in Poland. This need to preserve shipping access, protect from flooding and provide hydro-electricity has pushed the Polish authorities to initiate the construction of a major dam on the Vistula. Scheduled for completion 2020, this new project will come at a cost of €470m. This will obviously be a major new cause of fragmentation for the Vistula basin. AMBER scientists from SSIFI in Poland are currently building a large scale habitat simulation model for the Vistula. Given the width of the river, drone imagery has proven invaluable in qualitative mapping of flow and habitat types (**Figure 12**).

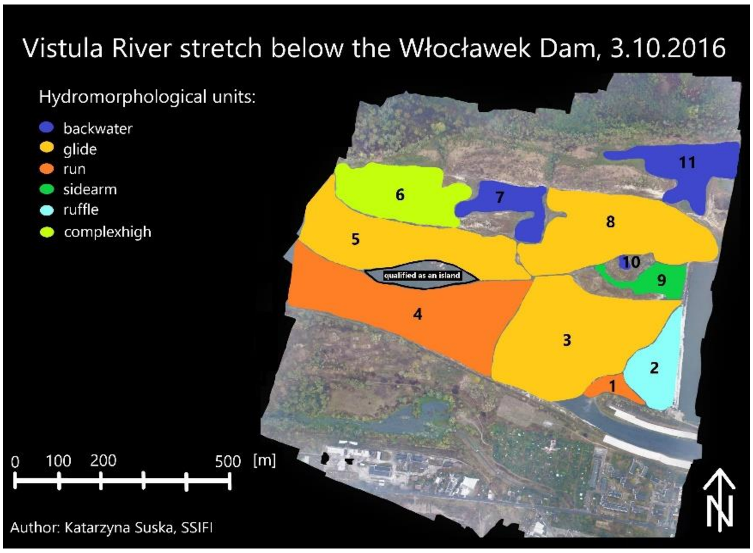

Figure 12. Habitat and flow type map, River Vistula.

4 EVOLVING DRONE LEGISLATION IN EU MEMBER STATES

4.1 Current regulations in the European Union

The continued usage of drones as a reliable and low-cost method for localised river corridor surveys and habitat monitoring is wholly dependent on the legislative framework that oversees drone operations. This section describes the current state of regulations on drone usage implemented across EU member states. Furthermore, it discusses the new EU-wide regulations that are slated for implementation in 2019\Q1. The European Aviation Safety Agency (EASA) currently has the mandate to oversee drone legislation across all member states. However, at the time of writing, the current EASA practice is to allow national airspace agencies to develop and implement their own drone regulations. Consequently, drone usage across the EU is now regulated by a patchwork of regulations that vary in severity and complexity. Here we list some key points of regulations (as of May 2018) across AMBER members with a particular emphasis on the operational conditions associated to river monitoring.

Denmark

Denmark airspace regulations are moderately permissive of drone operations. Drones are forbidden to fly over crowds of people (a grouping of 1000+ people) and are forbidden within 5 km of civilian airports or 8 km of military airports. Operations must be conducted in civil daylight hours (30 minutes before sunrise to 30 minutes after sunset) and pilots must keep the drone within visual line of sight. Drones must be kept at least 150 meters from inhabited areas but permissions can be obtained to reduce this distance. In Denmark, even leisure flying requires a registration process and commercial operations require permit. In terms of river surveys, these regulations are easy to follow and overall Denmark is a good theatre of operations for drones.

France

Since 2017, professional drone usage in France is more heavily legislated. In France, the term 'professional usage' is defined as any non-leisure usage. Therefore, research and environmental monitoring applications fall under this banner. In such cases, drone pilots must have passed the full theoretical examination for pilots of Ultralight Manned Aircraft. Practical skills are not examined. Certified pilots can then operate under four scenarios labelled S1 to S4 and defined in **Table 1**.

Table 1. French airspace flight scenarios for drones. MTOM gives the Maximum Take Off Mass for each flight scenario and BVLOS determines if operations where the drone is Beyond Visual Line Of Sight are permitted.

Scenario	Max Altitude [m]	Max Distance [m]	MTOM [kg]	Urban areas?	BVLOS?
S1	150	200	25	NO	NO
S2	50	1000	25	NO	YES
S3	150	100	4	YES	NO
S4	150	none	2	NO	YES

Germany

Germany implemented a comprehensive set of drone regulations in March 2017. These regulations are generally permissive, especially for drones below 5kg such as those typically used in environmental monitoring. Specifically, operations of drones below 2kg need no form of licensing, drones between 2 and 5kg need a to be registered and the pilot must demonstrate minimal theoretical knowledge. Furthermore, all drones must have a fireproof label with the name and address of the pilot. Flights below 100 meters in altitude and in Visual Line Of Sight (VLOS) do not require a permit. Flights are not allowed over urban areas and over people. However, German regulations have placed a complete flight interdiction on all nature reserves and on all waterways used for shipping. This restricts the potential usage of drones for river monitoring in German airspace.

Ireland

Irish airspace legislation has very specific provisions for drone usage. Unlicensed users are allowed to conduct drone operations within specific flight parameters. The drone must be kept below 120 meters in altitude, within a distance of 300 meters, further than 5km from an airport and away from settled areas. Users that wish to extend any of these flight parameters must apply for a *Specific Operating Permit.* This permit requires both a theoretical and practical course. Once obtained, certified drone operators can apply to the Irish Aviation Authority (IAA) for specific cases where the standard flight parameters must be transgressed. In terms of river mapping, these regulations are conducive to monitoring operations in unpopulated areas, but for river reaches in urban areas, a specific operating permit would be required.

Italy

After a series of incidents of irresponsible flying over some of Italy's major heritage sites (e.g. the Colosseum), Italy has developed strict drone operations legislation. The unique feature of this legislation is the definition of so-called 'critical zones' where all drone flights are forbidden. These critical zones include all urban areas, motorways, major roads and railways. Furthermore, pilots are classed in 2 categories: hobby flyers and professional flyers. In Italy, the category of a professional pilot is defined as anybody who uses a drone in the course of their work irrespective of whether or not a direct fee is charged for drone imagery or video footage. This therefore includes any scientist or river manager who uses drones for environmental monitoring. Neither category of pilot can operate in critical zones. Hobby pilots are restricted to an altitude of 60 meters and a distance from the pilot of 300 meters while professional pilots can operate at altitudes of 150 meters and at distances of 500 meters. However, all flights must be carried out in VLOS mode.

Netherlands

Dutch airspace regulations have a complex and layered approach to drone usage. Hobby operations are allowed within familiar caveats of VLOS operations, 120 meters maximum altitude and away from all infrastructure and people. However, commercial operations are very tightly controlled. As a basis, a drone pilot must have a pilot’s license for small or ultralight aircraft. Then companies using drones must have additional permits that vary according to the weight of the drone. The definition of commercial activities does not specifically include universities but it does clearly state that any use of the drone for financial profit or recompense falls under the commercial category. This definition is grey in regard to universities, but it would seem prudent to conclude that academic work of people who are employed by universities or river agencies would fall under the commercial category. In this case, the requirement for a pilot's license is a huge impediment and makes the use of drones for monitoring Dutch rivers an unlikely prospect.

Poland

Recreational drone usage is allowed in Poland within now familiar caveats of VLOS, altitude control, etc. However, Polish regulation adopted in 2016 clearly states that any institutional operations fall under the commercial category and thus permits are required for river monitoring work. However, once acquired, pilots can operate in both Beyond Visual Line Of Sight (BVLOS) and VLOS but only in unpopulated areas and away from aerodromes. This is therefore a suitable context for drone-based river monitoring.

Spain

Spain is arguably the most restrictive country for drone usage. Spanish drone regulations demand that the drone pilot have the full competence, both theoretical and practical, of a manned Ultralight Aircraft pilot. In practice, this has proven to be a quasi-insurmountable access barrier and the drone industry in Spain is therefore not well developed. Within Spain, drone-based river monitoring is currently not a realistic and cost-effective option which can replace more traditional ground-based methods.

United Kingdom

The UK Civil Aviation Authority (CAA) has a set of mature and well developed regulations for drone usage over UK airspace. The UK was the first UK member state to partition drone usage into hobby and professional/commercial usages. Hobby pilots in the UK can operate in VLOS mode up to altitudes of 120 meters. They must stay away from urban areas (at least 150 m) and aerodromes (based on airspace classification) and cannot fly over crowds of more than 1000 people. Commercial pilots must pass a bespoke course tailored to drone usage, they do not require a qualification for manned aircraft operations. Interestingly, the CAA defines commercial work as a direct contract of fees in exchange for the product of a drone operation. Academic and other institutions that may use drones as part of their mandate, but that do not charge a direct fee for their products, are not considered to be commercial operators. This greatly facilitates the use of drones for river monitoring.

4.2 Future regulations in the European Union

The patchwork of regulations described above reflect the fact that, currently, EU member states have competence over airspace regulations. In the specific case of drones, operations of drones below 150 kg falls within the jurisdiction of member states. However, it is now expected that in the summer of 2018, airspace regulations across the union will be harmonised and central authority will be passed to the European Aviation Safety Agency (EASA). This will include a mandate to provide harmonised drone regulations across all member states to be implemented in 2019. In preparation for the transition, EASA has developed a set of regulations for drone usage in EU airspace. These regulations are meant to insure:

- Safety, by keeping drones away from manned aircraft, people and critical and sensitive infrastructure;
- Security, by keeping drones at an appropriate distance from nuclear reactors, military bases or oil pipelines;

- Privacy, by means of a proper separation from residential areas, as no one wants a drone peering into their bathroom window; and
- Environmental protection, by reducing the noise level.

One ambitious feature of this legislative process is the establishment of so-called U-space. This is a term adopted by the EU commission for a low-level airspace (below 120m) accessible to drones and having full air traffic control infrastructure (much of it automated) allowing for safe drone operations in both remote and urban areas even in BVLOS flight mode. EASA has set a timeline for the implementation of these new regulations. In 2016, draft regulations were formulated. These were then released to the public in a process that culminated in an open consultation leading to changes in the proposed regulations. On February 6th 2018, EASA released an edited version of the proposed regulations that takes into account the results of the consultation process (Opinion 1/2018). The EU commission is now scheduled to adopt the change of function of EASA, making it the main regulating body of EU airspace, in Q4/2018. Final implementation of the proposed EU-wide drone regulations is scheduled for Q1/2019. In the longer term, full realisation of the U-space concept is planned for 2025.

The proposed regulations are based on a classification of drones into four types, C1 to C4. A unique feature of these regulations is that drone types are defined by both weight and intended operations scenarios. The regulations begin by defining operational categories of 'open', 'specific' and 'certified'. For the open category, the general rule is that operations are conducted in VLOS, below 120 m and with a drone of less than 25 Kg. Furthermore, three classes have been established within the 'open' category (**Table 2**):

- A1: flights over people but not over open-air assemblies of persons;
- A2: flights close to people, while keeping a safe distance from them;
- A3: flights far from people.

In the specific and certified categories, pilots will be required to submit a risk assessment for each specific operation. The exact administrative procedures for this remain under consultation.

Table 2. Summary table from EASA publication Opinion 1/2018.

Operation		Remote pilot competency (age according to MS legislation)	UAS				UAS operator registration
Subcategory	Area of operation (far from aerodromes, maximum height 120 m)		class	MTOM/ Joule (J)	Main technical requirements (CE marking)	Electronic ID/ geo awareness	
A1 Fly over people	You can fly over uninvolved people (not over crowds)	Read consumer info	Privately built	< 250 g	N/a	No	no
			C0		Consumer information, Toy Directive or <19 m/s, no sharp edges, selectable height limit		
		• Consumer info • online training • online test	C1	< 80 J or <900 g	Consumer information, <19m/s, kinetic energy, mechanical strength, lost-link management, no sharp edges, selectable height limit.		
A2 Fly close to people	You can fly at a safe distance from uninvolved people	• Consumer info • online training • online test • theoretical test in a centre recognised by the aviation authority	C2	< 4 kg	Consumer information, mechanical strength, no sharp edges, lost-link management, selectable height limit, frangibility, low-speed mode.	Yes + unique SN for identification	yes
A3 Fly far from people	You should: • fly in an area where it is reasonably expected that no uninvolved people will be endangered • keep a safety distance from urban areas	• Consumer info • online training • online test	C3	< 25 kg	Consumer information, lost-link management, selectable height limit, frangibility.		
			C4		Consumer information, no automatic flight	if required by zone of operations	
			Privately built		N/a		

Generally speaking, this new regulatory framework could prove to be highly supportive of river survey work. However, one major risk lies in the interpretation of the requirement for so-called 'e-identification'. This is a requirement for drones to actively emit their position and identification to nearby aircraft and airports. The intention is to facilitate detection in case a drone strays into busy airspace. From a technical perspective, deploying a device capable of such functions on a low-weight and low-cost drone remains a very significant challenge. Therefore, the exact implementation of this requirement will have to be carefully monitored and debated. Mandatory e-identification of all drones above 250 grams would prove to be a major challenge to all river survey work. It would likely result in a freeze in development for this type of drone activity for 1-2 years while drone manufacturers respond to the regulations. However, it should be noted that an immediate imposition of e-identification for all drones over 250g would in effect ban the most popular drones on the current market presently used both by hobbyists and scientists and thereby have very detrimental impacts on the growing drone market. It therefore seems unlikely that the commission would impose such drastic measures and the more probable scenario is one of a transition period that would allow for the development of the required technology. On a more positive note, these regulations could also be a huge enabling factor for drone-based river surveys in the EU. If the e-identification can be adopted in sensible stages, then these uniform regulations would put in place a union-wide set of flight regulations for drones. This means that rivers in countries like Spain and the Netherlands would become suitable for drone-based monitoring. It would therefore be possible to implement standardised drone monitoring protocols across all member states and thus collect structured data suitable for both management and scientific research. These new regulations are therefore a positive future change and they will enhance the profile of drone-based habitat monitoring and characterisation in the EU.

5 CONCLUSIONS

The state of the art technologies described above all have minimum requirements in terms of personnel training, skills and costs. In terms of drone technology, this low-cost platform has important potential applications for AMBER stakeholders. At its most basic level, the video imagery collected from drones can make a powerful contribution to citizen outreach and education efforts. Suitable drones can be purchased on the consumer market for less than 2000 euros. Interested stakeholders will have to carefully examine their local airspace legislation (section 4), but given the remote locations of most river reaches and consequently lower populations, legislation should not prove to be a major barrier in most cases once new EU-wide legislation on drone usage comes into force in 2019. The application of drones to habitat mapping and river management has varying requirements in terms of personnel, expertise and computer software depending on the type of desired outputs. For qualitative mapping, a user with expert knowledge can easily use high quality, high spatial resolution, drone footage and/or images to attribute habitat types to river reaches. This has no further requirement than the drone and basic computer facilities. In the case of quantitative mapping, entry requirements depend on the tasks. The first step in using drones for quantitative mapping purposes is image acquisition. For quantitative purposes, the geometry of drone flights must be carefully planned. This topic is discussed in Carbonneau and James (2017). Once acquired, the drone imagery will require processing with SfM-photogrametry in order to be useable for quantitative spatial measurements. The most commonly adopted solution is the use of commercial SfM packages such as Photoscan by Agisoft Inc., Pix4D Inc. or Recap Photo by Autodesk Inc. These commercial solutions now have a highly automated workflow and can be used with very little previous experience or knowledge. Alternatively, open-source solutions are beginning to appear. The leaders in this area are MicMac and the Open Drone Map project. Both these packages are fully functional open source solutions that can be used both for educational and commercial purposes. However, open source solutions are more difficult to implement for non-expert users and a steeper learning curve can be expected. Once the drone imagery has been successfully processed into image and topography products quantitative analysis can begin. This will require the use of Geographic Information Systems (GIS). In this case, we would recommend that new users move directly towards the open source solution QGIS. This is a fully functional and user-friendly GIS interface that will allow for measurement and analysis of orthorectified imagery and digital elevation models. For more advanced analyses, the associated package GRASS GIS, offers an open source solution capable of the more advanced tasks of depth mapping, grain size mapping and vegetation classification. However, readers should note that as requirements progress from simple mapping in QGIS to advanced tasks such as grain size mapping, the required skill levels of personnel will increase. Whilst drone operations only require a responsible pilot, effective implementation of advanced tasks requires M.Sc. level qualifications in a relevant discipline. In the case of satellite remote sensing for larger scale applications such as large catchments, we once again argue that freely available data with open-source processing solutions represents the most feasible way forward. The Sentinel-2 missions in the ESA Copernicus constellation of satellites deliver freely available image data. Great effort has been deployed by ESA in order to offer open solutions to data download and image preparation. The resulting product is currently leading the field in freely available remote sensing imagery surpassing the Landsat program in terms of quality, temporal and spatial resolution. The final products are readily compatible with QGIS and GRASS GIS. We argue that this combined usage of low-cost drones and freely available satellite can address most management needs in European rivers at the lowest possible cost.

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