Aerial photography collected with a multirotor drone reveals impact of Eurasian beaver reintroduction on ecosystem structure


Abstract: Beavers are often described as ecological engineers with an ability to modify the structure and flow of fluvial systems and create complex wetland environments with dams, ponds, and canals. Consequently, beaver activity has implications for a wide range of environmental ecosystem services including biodiversity, flood risk mitigation, water quality, and sustainable drinking water provision. With the current debate surrounding the reintroduction of beavers into the United Kingdom, it is critical to be able to monitor the impact of beavers upon the environment. This study presents the first proof of concept results showing how a lightweight hexacopter fitted with a simple digital camera can be used to derive orthophoto and digital surface model (DSM) data products at a site where beavers have recently been reintroduced. Early results indicate that analysis of the fine-scale (0.01 m) orthophoto and DSM can be used to identify impacts on the ecosystem structure including the extent of dams and associated ponds, and changes in vegetation structure due to beaver tree-felling activity. Unmanned aerial vehicle data acquisition offers an effective toolkit for regular repeat monitoring at fine spatial resolution, which is a critical attribute for monitoring rapidly changing and difficult to access beaver-impacted ecosystems.

Key words: Eurasian beaver (Castor fiber), ecosystem structure, wetlands, unmanned aerial vehicle, structure-from-motion, environmental monitoring and management.

Résumé : On décrit souvent les castors comme étant des ingénieurs ayant la capacité de modifier la structure et le débit des systèmes fluviaux et de créer des environnements de milieux humides complexes avec des barrages, des étangs et des canaux. Par conséquent, les activités des castors ont des répercussions sur une vaste gamme de services écosystémiques y compris la biodiversité, l’atténuation des risques d’inondation, la qualité des eaux et l’approvisionnement durable en eau potable. Au moment où un débat se déroule sur la réintroduction des castors au Royaume-Uni, il est crucial d’être en mesure de surveiller l’impact qu’ont les castors sur l’environnement. Cette étude présente les premiers résultats de validation de concept montrant comment un hexacoptère léger muni d’un appareil photonumérique simple embarqué peut servir à prélever des données orthophotos et des modèles numériques de surface (DSM) d’un site où on a réintroduit les castors. Les résultats préliminaires indiquent qu’on peut utiliser les analyses des orthophotos et des DSM à petite échelle (0.01 m) afin de déterminer les impacts sur les structures écosystémiques y compris l’étendue des barrages et des étangs reliés, et les changements de la structure de la végétation attribuables aux activités des castors relativement à l’abattage d’arbres. L’acquisition de données par les véhicules aériens sans pilote offre une boîte à outils efficace aux fins de la surveillance régulière récurrente à haute résolution spatiale,
ce qui constitue un attribut critique pour la surveillance des écosystèmes en état de changement rapide et difficiles à évaluer, écosystèmes sur lesquels les activités des castors ont eu un effet.

Mots-clés : castor d’Eurasie (Castor fiber), structure écosystémique, milieux humides, véhicule aérien sans pilote, structure par mouvement, surveillance et gestion de l’environnement.

1. Introduction

Beavers are the classic example of a keystone species, having a disproportionately large habitat modifying impact than may be expected from their abundance (McKinstry et al. 2001). Beavers are frequently described as ecological engineers (Hartman and Tornlov 2006), their greatest geomorphological impact being the construction of dams to impound water (Butler and Malanson 2005). Dam construction increases catchment hydrological storage capacity (Hammerson 1994; Hood and Bayley 2008), reduces stream velocity and peak discharge, altering flow regimes locally (Burchsted and Daniels 2014) and downstream (Polvi and Wohl 2012), so there is expected to be a positive impact on flood risk alleviation (Collen and Gibson 2000). Beavers also construct canals to facilitate safe access to foraging areas (Gurnell 1998), and the creation of wetlands and reduction in tree cover can increase biodiversity (see review: Rosell et al. 2005).

Eurasian beavers (Castor fiber) were once common across Europe. Populations were greatly reduced by human activities, particularly over-hunting (Collen and Gibson 2000), and were thought to be extirpated from the United Kingdom by the 16th century (Conroy and Kitchener 1996). Stimulated by the European Commission Habitats Directive, reintroduction programs have seen the re-establishment of Eurasian beaver colonies across northwest Europe (de Visscher et al. 2014), including Scotland (Jones and Campbell-Palmer 2014). In England, beavers are currently classified as a non-native species and there is currently only one (recently licensed) wild population, subject to a rigorous, five year monitoring program (Natural England 2015).

Knowledge of how beavers impact ecosystem services is vital for providing an evidence base to inform policy developments regarding both the reintroduction of C. fiber in the United Kingdom and the wider management of beaver-impacted ecosystems (Burchsted and Daniels 2014). However, much of the available research into the environmental and particularly geomorphological impacts focuses on the North American beaver (C. Canadensis) rather than the Eurasian beaver (C. fiber). While there are similarities between the two, differences in environment and behaviour, including that C. fiber is thought to undertake more limited building activity (Rosell et al. 2005), mean their impacts cannot be presumed to be directly comparable (Gurnell 1998; Rosell et al. 2005).

Studies have highlighted the value of image analysis to quantify landscape alteration by beaver activity, using data obtained from satellite or conventional aircraft platforms (Johnston and Naiman 1990; Townsend and Butler 1996; Butler 2002; Cunningham et al. 2006; Polvi and Wohl 2012; Malison et al. 2014). However, the acquisition of these data can be costly and the imagery hitherto analysed has had a relatively coarse spatial resolution (e.g., 7 m (Johnston and Naiman 1990); 30 m (Townsend and Butler 1996); 1–4 m (Butler 2002); 2.4 m (Malison et al. 2014)). Ground-based surveying can generate useful geomorphological information (Nyssen et al. 2011; Burchsted and Daniels 2014; de Visscher et al. 2014); however, detailed ground-based surveying can be time consuming, challenging in complex wetland environments, and risks disturbing the study habitat (Shuman and Ambrose 2003; Chabot and Bird 2013). Beaver activity is a dynamic, year-round process (Collen and Gibson 2000); in particular, the construction and alteration of dams and canals can rapidly alter channel geomorphology and water storage (Halley 2011; Loeb et al. 2014). Consequently, infrequent sampling, for example, yearly or greater (Johnston and Naiman 1990; Wright et al. 2002; Polvi and Wohl 2012; Malison et al. 2014), may fail to capture the rate and extent of ecosystem change.

Recent research has highlighted the emerging use of unmanned/uninhabited aerial vehicles (UAVs or drones) in spatial ecology (Anderson and Gaston 2012) for environmental monitoring and management (Rango et al. 2009) including in impenetrable wetlands (Chabot and Bird 2013). UAVs may offer a cost- and time-efficient surveying option (Castillo et al. 2012; Colomina and Molina 2014), which can also yield three-dimensional (3D) models quantifying ecosystem structure, using techniques, such as structure-from-motion (SFM) photogrammetry (Turner et al. 2012; Lucieer et al. 2013).

This study presents early “proof of concept” research, using a digital camera mounted on a UAV and subsequent data processing to generate orthophotos and digital surface models (DSMs) to assess the potential of this approach to characterise the environmental impacts of beaver reintroduction.
2. Materials and methods

2.1. Study site

Research was undertaken at the Devon Beaver Project site, situated upon a small first-order stream in the headwaters of the Tamar river catchment, within Devon, South West England (DWT 2013). The site experiences a temperate climate with a mean annual temperature of 14 °C and mean annual rainfall of 918 mm (Met Office 2015). In March 2011, a pair of Eurasian beavers was introduced to a 1600 m² enclosure, dominated by a single channel, with land cover of deciduous willow and birch woodland. Beaver activity at the site has created a complex wetland environment, dominated by ponds, dams, and an extensive canal network (DWT 2013).

2.2. UAV platform and flight details

The UAV overflight of the study site was undertaken in December 2014 to minimise occlusion of the terrain and underlying hydrological system by the deciduous vegetation canopy. Fifteen iron-cross ground control points (GCP) (Fig. 1f, size 0.3 m diameter) were deployed across the site and geolocated using differential GPS. The UAV platform was a 3D Robotics Y6 hexacopter (http://3drobotics.com/) equipped with a GPS receiver and consumer-grade camera (Canon S100) and controlled by ArduCopter software (v3.2; http://copter.ardupilot.com). The site was gently sloping with a variation in terrain height of approximately 20 m (~180 to ~200 m above sea level). Automatic flights were designed using Mission Planner (v1.3.11; http://planner.ardupilot.com/), flying a lawnmower survey pattern with an average altitude of 25 m and average ground sampling distance of 0.01 m. Flight plans were designed so that every part of the area of interest was imaged in 10 or more photos. The camera was triggered at distance intervals to attain 70% front-lap and 65% side-lap, capturing 476 geotagged photographs in total. Camera shutter speed (Tv) was faster than 1/800 s, ISO (Sv) was 400, aperture (Av) was f3.5 and focus was set at infinity. To minimise shadowing, flights were completed within a few hours of midday. The area of interest was surveyed in three separate flights (due to platform endurance limits), with a combined flight time of under an hour.

2.3. Data processing and analysis

SfM reconstruction and orthophoto stitching was undertaken using Agisoft’s PhotoScan (v1.0.4; http://www.agisoft.com/); PhotoScan is described further in Verhoeven (2011), Remondino et al. (2014), and Kaiser et al. (2014). Ninety-two percent (436 photos) of the original image set was utilized in the reconstruction; the remaining images could not be matched because of insufficient tie-points, usually in more densely vegetated areas. Each GCP appeared in between 7 and 24 images (average 13); these GCPs, which were used to guide the reconstruction, had an overall root mean square error in 3D of 0.49 m. This error was dominated by the z component; the root mean square errors of x and y were 0.21 and 0.12 m, respectively.

The resultant point cloud (3D dataset) comprised 114 million individual points with spatial (x, y, z) and spectral (R, G, B) information. Points were meshed (Delaunay triangulation) using a height field, and the mesh regularly sampled to derive a DSM at 0.01 m resolution. The orthophoto was manually examined to determine whether key environmental features associated with beaver activity could be identified. Features were manually identified and digitized using a geographic information system (Esri ArcMap v10.2; http://www.esri.com/software/arcgis).

3. Results

Figure 1a presents the georectified orthophoto of the site, indicating the locations of several examples demonstrating beaver activity. Figures 1b and 1c show that the 0.01 m spatial resolution imagery is suitable to determine different occurrences of woodland disturbance. Figure 1b depicts a tree that has been completely gnawed through and felled, whilst Fig. 1c shows a live tree stem where early stage nibbling has occurred. Figures 1d and 1e illustrate the capacity of fine-spatial-resolution image data to identify beaver modifications to watercourses and channel geomorphology. In Fig. 1d, a beaver dam is clearly visible along with the extent of impounded surface water. Extensive canal networks have been created by beavers across the site, facilitating safe access to new foraging ground; a section of one canal is shown in Fig. 1e.

Figure 2 provides an example of the quantitative detail that can be extracted from SfM-derived topographic models. Figure 2a is a photo taken from the ground of the area of interest whilst Fig. 2b shows the same area captured from the UAV. Using the airborne orthophoto, it is possible to digitize the surface area of impounded ponds; for example, the pond depicted in Fig. 2b has a surface area of 125 m². The ecosystem structure can be further quantified from the DSM; for example, Fig. 2c depicts a high-spatial resolution DSM of the same pond, from which the maximum height of the dam has been completely gnawed through and felled, whilst Fig. 1f shows that the 0.01 m spatial resolution imagery is suitable to determine different occurrences of woodland disturbance. Figure 1b depicts a tree that has been completely gnawed through and felled, whilst Fig. 1c shows a live tree stem where early stage nibbling has occurred. Figures 1d and 1e illustrate the capacity of fine-spatial-resolution image data to identify beaver modifications to watercourses and channel geomorphology. In Fig. 1d, a beaver dam is clearly visible along with the extent of impounded surface water. Extensive canal networks have been created by beavers across the site, facilitating safe access to new foraging ground; a section of one canal is shown in Fig. 1e.

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Fig. 1. Georectified orthophoto at 0.01 m resolution, depicting (a) the enclosure; (b) the gnawed-through stump and trunk of a felled tree; (c) the partially nibbled trunk of a standing tree; (d) one of the new dam structures and resultant pond; (e) section of canal network; and (f) iron-cross GCP targets with black and white segments (size 0.3 m diameter). Yellow annotations highlight features discussed in results. All sub-figures are orientated north, whilst scale is presented in metres (m) for each sub-figure.
Fig. 2. Close-up of the pond depicted in Fig. 1: (a) photograph of the dam structure taken from the GCP marker a few metres west of the dam, (b) digitized extent of surface water, and (c) DSM of the dam and impounded pond (with digitized extent of pond from Fig. 2b).
face (1.44 m) can be determined. Additionally, because bed surfaces can be visible through the water, with further processing it may be possible to quantify bathymetry from a digital terrain model (Tamminga et al. 2014).

4. Discussion

Preliminary results presented demonstrate the suitability of a one-day UAV campaign to provide multiple data products characterising ecosystem structure as impacted by beaver activity. Evidence from this study suggests that: once procured and operational, UAVs allow rapid, regular, and cost-effective monitoring. This is of particular relevance to monitoring the impact of beavers, with research and field observations noting the rapid rate of ecosystem change, resulting from dam and canal building activities (Collen and Gibson 2000). In particular, UAV surveying mitigated many of the challenges associated with ground-based surveying in these environments, minimising habitat and species disturbance and personal safety risks associated with physically accessing wetlands. The low-altitude overflights enabled collection of fine spatial resolution imagery (∼0.01 m ground sampling distance), better than that readily available from satellite or manned flights (Johnston and Naiman 1990; Butler 2002; Malison et al. 2014), which would preclude the identification of many features visible in the presented imagery. As such, from manual analysis of the orthophoto, features characteristic of the main environmental impacts of beaver activity were readily identifiable. Clearly, UAV surveys offer a valuable means of data acquisition to develop a spatially explicit evidence base of beaver impacts to inform management and policy decisions.

Whilst the analysis presented yielded promising results, further work is required to determine the full potential and limitations of this monitoring approach (Whitehead and Hugenholtz 2014). The manual identification of features is useful as an illustrative example of the suitability of the application. However, whilst practical for small areas, it presents a barrier to upscaling monitoring to greater spatial or temporal scales (Blundell and Opitz 2006; Blaschke 2010). Automated classification of water surfaces (Sawaya et al. 2003; Baker et al. 2006) is hindered by occlusion due to vegetation cover, while spatially variable illumination (Singh et al. 2012) makes it challenging to automatically identify freshly chewed trees, indicative of recent woodland disturbance. Further work is required to explore the suitability of automated classification of the derived information products; this is likely to yield a semi-automated system presenting candidate areas to an operator, expediting feature identification. The use of SFM photogrammetry in environmental research is still an emerging field and the spatial uncertainty of the approach is determined by flight- and site-specific factors that need deeper empirical investigation (Bemis et al. 2014; James and Robson 2014). Previously, terrestrial light detection and ranging (LiDAR) scanning has been used to assess results produced from SFM (Kaiser et al. 2014; Ouédraogo et al. 2014). The combined use of these two techniques on control areas of the site may allow the use of SFM to be evaluated.

Beaver-impacted sites are complex, characterised by extensive vegetation cover and large areas of standing water, making it a challenging environment to reconstruct as a 3D model using SFM. However, the derived 3D models have great potential to extract terrain models characterising topographic and vegetation structure, pond bathymetry, and channel morphology, and to support hydrological modelling. These techniques offer exciting possibilities for investigating beaver impacts (and other environmental applications) over the short time periods that environmental change can occur.

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