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Flight elevation and water clarity affect the utility of unmanned aerial vehicles in mapping stream substratum

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Effective conservation and management of fish populations usually require an assessment of their habitats. The spatial extent largely depends on the species' space use, ranging from just a few metres in the Devil's Hole pupfish *Cyprinodon diabolis* Wales to thousands of kilometres in Chinook salmon *Oncorhynchus tshawytscha* (Walbaum). This variation ultimately dictates which methods are suitable to obtain information about their habitat use. Direct measurements of habitat features are usually preferred but may be unattainable for wide-ranging species. Across such large spatial expanses, fisheries biologists are increasingly using remote sensing techniques (Dauwalter, Fesenmyer, Bjork, Leasure, & Wenger, 2017). Aerial, satellite and spectral imagery are readily available for most of the earth's surface and provide valuable information on the physical environment in and around aquatic habitats (Dauwalter et al., 2017).

However, for certain applications the spatial and temporal resolution and photographic quality of satellite and aerial images can be a limiting factor. Unmanned aerial vehicles (UAVs or drones) may provide a flexible bridge between remote sensing techniques and on-the-ground mapping (Hodgson, Baylis, Mott, Herrod, & Clarke, 2016). The use of UAVs may be particularly useful when one requires more detailed images than what is available from aerial photography, and across larger spatial extents than is feasible to cover on the ground (Tyler et al., 2018). UAVs are increasingly being used in studying aquatic organisms and have recently been employed in quantifying jellyfish aggregations in marine habitats (Schaub et al., 2018) and identifying individual taimen *Hucho taimen* Pallas in Mongolian rivers (Tyler et al., 2018).

Here, an application of UAV-borne aerial videography to map spawning habitat of adfluvial brown trout *Salmo trutta* L. in Southern Norway is reported. Brown trout shows strong preferences for the physical characteristics of a spawning site, whereby substratum size, water depth and current velocity are the three main variables most frequently used to describe habitat selection. Of these variables, substratum size is frequently used as a proxy for the combined characteristics because it is easy to quantify in the field. In viewing the substratum on video, it was hypothesised that footage quality, and hence the utility of UAV videography, depends upon water clarity, weather conditions and flight elevation (see candidate models in Table 1).

To obtain high-resolution data over relatively large distances, a commercially available DJI Phantom 4 Pro quadcopter was used, equipped with a 20 Mb digital video camera with a 2.8–11 varifocal lens with a maximum 84° field of vision (DJI, Shenzhen, China). This permitted the recording of continuous footage of the rivers and to play back the video for assessment of substrate size distributions. Flights took place when there was sufficient light to show the details in the substratum, and a polarised filter in combination with a UV filter was used to cut surface glare. Observations of the substratum were only possible in relatively shallow reaches, which characterise typical spawning depths of brown trout (≈50–150 cm deep in this study), where water clarity permitted light penetration and where surface turbulence or wind did not obstruct the view. All footage was recorded in September and October 2017. Despite efforts to optimise the conditions for footage quality, there were variable light and weather conditions during the recordings, and the rivers varied in terms of water clarity, amounts of mosses and aquatic vegetation and dominant substratum sizes.

To quantify the conditions that controlled the perceived quality of the footage (the response variable), eight fisheries scientists were asked to score a 20-s sample of the footage from 32 rivers on a five-point Likert scale, with an emphasis on whether they could discern the composition of the substratum (minimum–maximum diameters

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from coarse pebbles to medium boulders = 16–512 mm). Predictor variables to explain the variation in mean perceived footage quality pertained to factors that could affect the viewer's ability to see the substratum, such as water clarity and distance from the camera. Total organic carbon and calcium concentration (mg/L), weather (sunny or overcast) and elevation of the drone (low-intermediate-high) were thus included as predictor variables. All measurements were taken at the time of footage except for water chemistry from two rivers, which were obtained from a water resources network database (www.vann-nett.no). Other factors could conceivably contribute to the quality of footage, such as water depth, air quality and light intensity, but those variables were not available.

An a priori set of simple and multiple linear regression models was constructed to explain the variation in mean score (Table 1). The best supported model included TOC concentration (95% CI [−0.303, −0.0876], $t = -3.71$ and $p = .0009$) and drone flight elevation (95% CI [−0.962, −0.0368], $t = -2.21$ and $p = 0.035$), where higher concentrations of TOC and higher elevation of the drone caused a decline in the mean score (Figure 1). The TOC and flight elevation were negatively, but insignificantly correlated (Pearson correlation coefficient $r = -0.236$ and $p = 0.19$). Fit was not improved by adding weather to the model (r^2 remained at 0.35).

TABLE 1 Models to describe variation in mean footage quality score. Footage was obtained using a DJI Phantom 4 Pro quadcopter equipped with a 20 Mb digital video camera

Model	R^2	*AIC*	w_i
TOC concentration	0.240	0.42	0.13
Calcium concentration	0.160	3.83	0.02
Flight elevation	0.040	7.87	0.00
Weather	0.001	9.21	0.00
TOC concentration + flight elevation	0.350	−2.55	0.58
TOC concentration + weather	0.240	2.42	0.05
TOC concentration + weather +flight elevation	0.350	−0.57	0.21

The best supported model makes qualitative sense: water clarity decreases with increasing TOC concentration, thus obstructing visibility of the substratum, whereas greater flight elevation makes discerning substratum composition increasingly challenging. Surprisingly, weather had no effect on perceived footage quality. Although sunshine may yield more light and hence more information to each picture frame, it increases contrast, whereby the darker outlines of the substratum are obscured. For the purpose of describing the variation in substrate size, the interstitial space between rocks is important. Starker contrast and less visible space between rocks might therefore reduce the benefit of more light. Conversely, overcast skies cause an even dissipation of light, which offset the reduced light intensity relative to sunny conditions.

Optical methods for remote sensing require a clear line of sight through whichever medium. For terrestrial applications, fog and precipitation can obstruct the view and the quality of the footage. In aquatic settings, the clarity of the water plays an additional role in determining how well the method works (Marcus & Fonstad, 2008; Schaub et al., 2018). TOC concentrations can be high in boreal rivers and may therefore affect the utility optical methods in mapping in-stream habitat features. The results showed that TOC concentrations exceeding 10 mg/L and at flight elevations exceeding 15 m above the surface were associated with low perceived quality. Although the focus was on TOC in the present study, other sources can reduce clarity and pose a similar challenge to optical methods.

The potential utility of UAVs in mapping aquatic habitats is apparent from the present study. Indeed, a rapidly increasing number of available UAVs contribute to lowering the price to the level that their use is no longer cost-prohibitive (Woodget, Austrums, Maddock, & Habit, 2017). When used under favourable conditions, UAVs can represent a useful addition to the quiver of tools used in aquatic

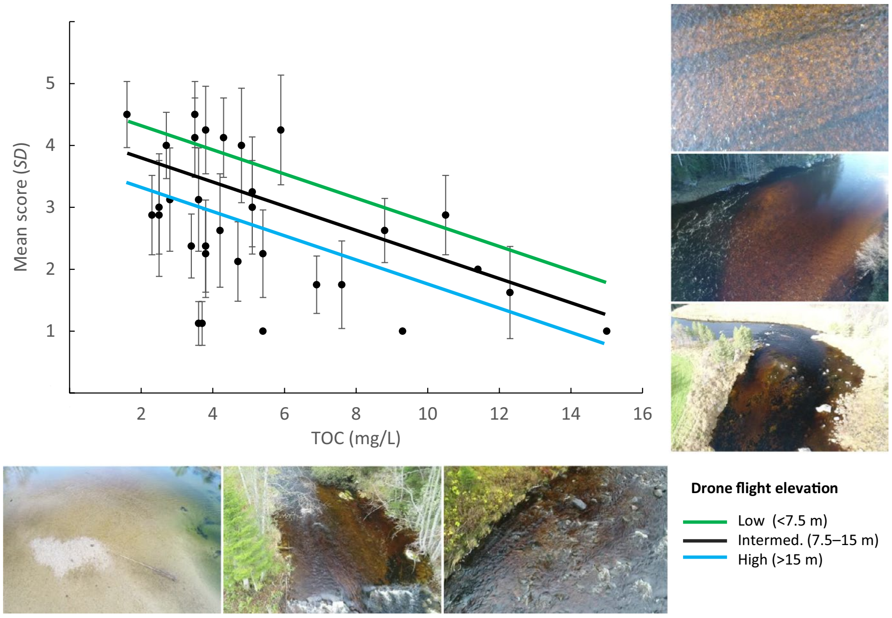

FIGURE 1 The influence of total organic carbon (minimum–maximum = 1.6–15.0 mg/L) and drone flight altitude (low, intermediate and high) on mean perceived footage quality (1 = worst and 5 = best) from the best approximating model. Error bars depict standard deviations of the mean score for each river. Bottom picture panel shows, from left to right, increasing TOC concentrations at low elevation flight. Right panel shows footage at different flight elevations for similar TOC concentrations (min–max = 4.7–5.1 mg/L). All photos © Kjetil Rolseth

habitat mapping and may be used to build orthophotos and quantify substrate size distributions (Tyler et al., 2018). A major strength of this approach is that geo-referenced footage can be stored for future evaluations (Marcus & Fonstad, 2008), which may serve as important baseline information in the face of chronic pressures on rivers and riparian ecosystems.

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