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Published in:
Environmental Technology (United Kingdom)

DOI:
10.1080/09593330.2020.1824022

Publication date:
2022

Document version:
Accepted manuscript

Citation for pulished version (APA):
Svane, N., Flindt, M. R., Petersen, R. N., & Egemose, S. (2022). Physical stream quality measured by drones and image analysis versus the traditional manual method. *Environmental Technology (United Kingdom)*, *43*(8), 1237-1247. https://doi.org/10.1080/09593330.2020.1824022

Physical stream quality measured by drones and image analysis versus the traditional manual method

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Abstract

Information of the physical and ecological state of streams along with an overview of the need for maintenance is traditionally a time-consuming manual field task with subsequent limitations in area coverage. Here we propose a novel approach to stream monitoring and management using a low-cost Unmanned Aerial Vehicle (UAV) platform to collect data comparable to that from traditional monitoring schemes. This technology provides high resolution imagery while being easy to implement at a low cost along with providing data that represent the stream in both fine scale and at landscape scale. The results show a significant correlation between results obtained by the two methods, with the largest difference in DFI-values being ten, but in many cases being < five. The UAV-method is especially strong in supporting geographical measurements of stream width and course along with certain stream parameters such as physical variation, water flow and gravel coverage. The results indicate that UAV mapping of streams is a feasible alternative or support to the traditional mapping of certain open stream types with the possibility of covering more area with the same time-use.

Keywords

Drones, remote sensing, stream biology, environmental mapping, freshwater

Introduction

Fresh water systems consisting of stream networks are highly important as they both provide a range of natural services such as being habitats for flora and fauna [1] or spawning ground for fish [2], along with an aesthetic, recreational and practical value for humans [3]. It is therefore of high importance to maintain or obtain a good ecological status [3, 4] in the stream systems for example by restoration and monitoring efforts [5]. To preserve or improve the ecological quality of the freshwater systems political initiatives like the European Water Framework Directive (EU WFD), [4], have been introduced. All European countries are obligated to fulfill the EU WFD which is implemented through the national programs of measures [6] and specific regulations made in the local municipalities in accordance with the national stream legislation [7].

The EU WFD states that all streams should obtain “Good” ecological status which is determined from fauna analyses and chemical measurements. In the local stream regulations management to achieve or maintain good environmental status is implemented through quality objectives called A-E. These cover: A) Streams of a scientific value, B_{1-3}) Streams with good conditions for salmon-spawning, adult salmon or adult carps, C) Streams for water drainage, D) Streams affected by wastewater, E) Streams affected by water reclamation [8]. To obtain a good ecological status in streams it is necessary to improve the chemical and physical conditions which in turn will improve the conditions for stream fauna which is the basis of the stream quality assessment [3, 9]. Thus, the physical state of a stream is both important for stream fauna (i.e. ecological state) and the rate of flow [10] which is why a great deal of focus and an extensive monitoring programs exist in this sector. Traditionally local stream management in Denmark is based on the Danish Physical Index [11] and the Danish Stream Fauna Index (DVFI) [12, modified by 13] along with maintenance through vegetation cutting, sediment removal or restoration measures such as removal of obstructions, re-meandering etc. [5]. The municipalities perform a manual estimation of the physical state of sections of most of the local streams on a yearly basis covering a total of app. 1000 stations [14]. This procedure is relatively time consuming both due to the length and number of streams and a sometimes-limited accessibility. The combined length of streams with established objectives included in the Danish water plans is 18,375 km [15] thus providing a large base for optimization of the monitoring effort. An index similar to the Danish Physical

Index has been developed in the UK and tested or adopted in several other European countries and this includes an even more thorough monitoring of the streams/rivers and surrounding areas [16, 17]. As this index include many physical, geographical and land-use relevant parameters the drone-method is expected to be relevant here as well. As more countries in Europe have a greater number of large rivers and river systems, the method might even be more relevant in these places.

The traditional method of determining the physical index of a stream is based on 17 physical parameters that is noted 10 times in 3x100m sections of the stream [11]. The efficiency of the method for determining the ecological quality of streams is not well described in the literature, but some inter-surveyor variation in estimation of the parameters has been described [18].

This procedure is thus limited in the length of the stream that is actually surveyed and the method does not include information about land-use in a greater distance than 10m on each side of the stream. Therefore, development of techniques to support and/or complement the existing methods is of interest and needed to improve the information level, cost-effectiveness and number of streams monitored. In this project we propose using a drone-based method as a supplement for the standard method of estimation of the stream physical index. This method is chosen as streams often stretch over large areas thus using drones, we hope to gain a higher spatial resolution along with more detailed information of the surrounding area. Equally some streams are more or less inaccessible due to vegetation, muddy surfaces, fencing or other obstacles which makes drone based remote sensing a feasible solution for collecting data in these areas. By using multi rotor drones we secure a flexibility in the mapping process enabling both low altitude high resolution images and film for ground truthing along with high-altitude low-resolution images for mapping. The endpoint is a low-cost solution providing large scale data sets at a low time consumption which eventually can be implemented as a supportive method for stream monitoring in the municipalities.

Remote sensing in the ecological field has historically consisted of satellite and aerial plane-based imagery with a limited resolution and a limited focus on a local scale [19]. In the last few years, a new segment in remote sensing based on Unmanned Aerial Vehicles (UAVs) has emerged and since grown constantly providing a valuable tool in mapping and inspection. UAVs are beginning to be accepted as tools in many scientific branches with areas of use that are widespread and covers agricultural and forest mapping, archeological surveys, volumetric measurements, 3D modelling, coastal surveys, invasive species mapping and more [20, 21, 22]. In stream specific studies drones have been used for defining bathymetric conditions using Structure from Motion (SfM) photogrammetry [23], depth estimation of vegetation [24] and thermal applications [25]. Often are images and data solely collected using an RGB camera but sensor attachments such as Near Infrared (NIR) sensors, thermal cameras or chemical sensors are beginning to be more widely implemented [26, 27, 28].

Data processing of remote sensing data covers a range of approaches with different levels of complexity: 1) a purely visual interpretation of the data by an expert, 2) a parameterized interpretation based on direct GIS-measurements, 3) a computer-based interpretation of image information based on pixels or image objects [29] , or 4) a machine learning approach using classification algorithms like Support Vector Machines [30] or a neural network approach [31].

In this project we aim to establish if there are any advantages by performing stream monitoring based on drone-imagery using visual bands and GIS-based measurements. Specifically, we want to determine how well the drone-based method performs compared to the standard method for determining the ecological state of a stream by using physical parameters. Based on initial tests we expect that the two methods will perform equally well, and that drone-monitoring is especially effective in making objective, accurate, GIS-based surveys. The method is also expected to provide new supportive parameters such as classification of the catchment area. We expect that some data-processing can be automated but that this step is very complex and might be superfluous in a simple monitoring methodology.

Methods

In total 21 stations in seven Danish streams were mapped in May and August 2016 and 2017. In each stream three stations of 100 meters length were chosen according to the standard DFI manual method [11]. In this index the DFI-values ranges from -12 to 63 with most common values being between -5 and 45 [32]. The values correspond to stream quality classes in a loosely defined scale with overlapping values: High quality:

> 38, Good quality: 25-40, Moderate quality: 13-30, Poor quality: 0-15, Bad quality: -12-5 [33]. Table 1 gives a summary of the main characteristics for the streams monitored in this project.

Table 1 near here

Stream Tude (TUD) is located on Sealand, Humbaek (HUM), Vibaek (VIB) and H35 (H35) in Southern Jutland and Fraugde Baek (FRA), Seden Baek (SED) and Daltofterenden (DAL) on Funen. The specific streams were chosen because of variations in their physical parameters, course, size and catchment type along with variations in historic DFI values. The aim was to test the method on streams with expected DFI values ranging from low (< 0) to medium (15-25) and high (25-35).

Due to local obstacles, surrounding forest or the general course of the seven streams the stretch mapped by drone varied from 305 m (HUM) to 1262 m (TUD). The course and cross section varied from channelized (SED) to natural (HUM, FRA). The stream velocity ranged from still and slow (0 – 0.10 m/s) (SED, DAL) to semi-fast (app. 0.5 m/s) (FRA, HUM) and substrate from mud (SED, DAL, VIB) to gravel and stones (FRA). The near-stream catchment types varied from natural (H35) to a mix of nature and agriculture (VIB), grazing (SED, DAL, FRA) or only agriculture (HUM). Information about the required objectives of the streams was only available for the streams in Sealand (B_2) and Southern Jutland (all B_1). The required stream width ranged from 0.5 – 0.7 m (H35) to 3 m (TUD). To validate the difficulty of mapping the specific streams due to their surroundings, vegetation growth, course, etc. a simple rating (from very easy to very hard) was performed.

Technical setup

All flights were performed in compliance with the current Danish legislation consisting of the Act of Drone flight in built up areas [34] and the Act of drone flight outside built up areas [35] by a certified drone pilot. The flights were always performed as VLOS (within Visual Line Of Sight) with a distance to the UAV never exceeding 400 meters. The UAV platforms used in this project were both consumer grade platforms with no sensor upgrades. The model used at Tude Å (2016) was a DJI Phantom 3 Professional with the standard 1/2.3” CMOS sensor with 12.4 million effective pixels and a field of view of 94° at a 20 mm f. 2.8 aperture

[36]. The platform used at all other streams (2017) was a DJI Phantom 4 Professional with the standard 1'' CMOS sensor with 20 million effective pixels and a field of view of 84° at an 8.8 mm/24 mm f. 2.8 – 11 apertures [36]. On both platforms, the camera was mounted in a shock-buffered gimbal and could be turned front to back -90 to +30 degrees. Films used as supportive data were recorded in 1080x1920 resolutions at 30 frames per second. High capacity 4S LiPo (lithium-polymer) batteries of 4500-5870 mAh were used providing a *practical* flight time of 22-25 minutes depending on the drone. For security reasons, no battery was used below the 20 % mark which equals to an approximate flight time of 20-22 minutes. A total of 2-4 batteries were used per stream as the areal coverage per battery at 100 meters altitude equals 10-20 hectares. For low altitude mapping one battery covered two transects of 500 m length.

Field work (drone-based)

All images for the base maps were obtained with the camera pointing downwards at an angle of 90 degrees (nadir). The camera gimbal secured a uniform image collection even at maneuvers at speed. In each area, images were collected from an altitude of 100 meters above ground (pixel size of 2.4 cm w. Phantom 4, 3.8 cm w. Phantom 3). These images were subsequently used for generation of georeferenced maps of the areas with a geographical error of approximately 3-5 meters in the X-Y plane. The images were collected by flying two parallel transects following each brink of the streams. This permitted sufficient overlap between images which is required to be 60 % sidelap and 80 % overlap as a minimum [37]. The images were collected by manually activating a shutter button on the remote control and continuously changing image parameters to suit the environmental conditions with consistent contrast in the images. This approach secured a uniform dataset and a high quality of the resulting maps even though applications for automatic mission planning exist. Images from an altitude of 6-10 meters (a minimal pixel size of 1.6 mm) were collected for mapping of fine scale features such as sediment type, physical features, vegetation types, hanging vegetation, roots etc. For determination of stream velocity, a film was recorded from an altitude of 6-10 meters and the velocity estimated visually as per the standard method [11].

The complete workflow from data collection to analysis is shown in figure 1.

Figure 1 near here

Field work (standard method)

Following the standard DFI procedure [11] 17 parameters were described to estimate the physical quality. These parameters were divided into groups in relation to their focus area (e.g. stream shape, substrate, vegetation, flow) and each parameter were given a scale-value (L: 0-3) which was multiplied by a fixed factor (F: -2 to +2), which resulted in a corrected value (= LxF) and summed up to the final DFI value.

Data processing and analysis

The procedure was the same as with the standard method only using images as the sole data basis. Parameters such as substrate type, submersed vegetation and riffles and pools which in a few cases could not be determined from images due to shading by overlying vegetation or reflection in the surface were in these cases left out of the calculation. Substrate type was not possible to determine for one stream (SED) due to reflection. One stream (TUD) was partly covered (23 %) by overhanging vegetation thus here the stations was placed in clear passages. Two streams (H35 and VIB) were impacted by a layer of either emergent vegetation or floating algae which made determination of substrate type harder. One stream (HUM) was impacted by shadowing because of a very low-lying course with steep banks.

The image software Agisoft Photoscan version 1.3.2 build 4205 64-bit [37] was used for stitching singular images into complete georeferenced maps. The software also provided modules for creating Digital Elevation Maps (DEM) from dense clouds which are derived from Structure from Motion data [23, 37]. The workflow of the stitching and export process was performed as described in the Agisoft Photoscan Professional User Manual [37] and all data was exported as georeferenced (UTM ETRS89 32N) .tiff files. The settings used for alignment were: High Accuracy, Generic and Reference preselection, Key Point limit of 40,000 and Tie Point Limit of 4,000. The resulting sparse cloud was then processed into a 2.5D mesh and then an ortho-mosaic with a Ground Sample Resolution (GSD) of 2.4 – 3.8 cm depending on the drone used.

All measurements of stream width, degree of meandering and width of stream-near areas along with coverage calculations of vegetation were performed measuring the parameters using the GIS software

MapInfo Professional version 11.5 [38] from the basis 100 m raster map. For the vegetation calculations the low altitude images were used as a support for specifying the vegetation type. All other parameters were estimated from the low altitude images, both recorded in an angle of 90 degrees or at an angle of 40 degrees (i.e. cross section of the stream) and written in the GIS layer.

The data was processed such that both direct comparisons between the methods could be made but also, so a subjective validation of the drone method could be done. Figure 1 describes the actual method used to estimate the DFI value for the single parameters using the drone data. For 50 % of the parameters (8) a combination of GIS measurements and visual observations on the pictures were used – primarily for substrate and vegetation parameters. Measurable parameters like stream width variation, vegetation coverage etc. was solely estimated by GIS (5 parameters) and finally 4 parameters were only estimated by visual observations on the pictures. To make a tangible estimate of the uncertainty of parameter recognition using the drone-based method a scale from 0 % (no uncertainty) to 100 % (maximum uncertainty) was set up. This was based on an assessment by two experts with a biology-background in which they were asked to rate the parameter recognition in the following uncertainty intervals: 0-25 %, 25-50 %, 50-75 % and 75-100 %. For some parameters (i.e. meandration, coverage estimations, direct measurements) the assessment was made after post processing (generation of a stitched survey map) and for the rest the assessment was based on a visual estimation.

A statistical linear regression test on the comparison of methods was performed in SigmaPlot v. 12 [39] using an alpha-value of 0.05.

Results

To determine how well the drone based DFI match DFI data collected by the standard method a simple linear relation between the datasets was made (Figure 2). The relationship shows a strong and significant relationship with a R^2-value of 0.76 and $P < 0.001$. The monitored streams have values of physical quality ranging from 2 (DAL) to 26 (HUM) using the standard method, whereas for the drone method the values range from -4 (DAL) to 31 (HUM). All three stations in Daltofterenden have very low DFI values (< 5) with the drone-method scoring lower values for all stations. All three stations in Seden Stream also show low DFI values (< 6) but in this case the drone-method scores higher than the standard-method. The stream that scores highest DFI values (> 21) in all stations is Humbaek with the drone-method scoring higher in all stations. The largest deviance between the two methods is seen in one station in H35 (diff. of 10) and one in Fraugde Baek (diff. of 8) with the standard-method scoring higher in H35 and the drone-method scoring higher in Fraugde Baek. The best matches between the two methods are all stations in Stream Tude, two stations in Vibaek, two in Seden Baek, two in Daltofterenden, one in Humbaek with values with no or very low deviation (max. +/- 1).

Figure 2 near here

The streams with high and low deviation between methods cover both traditional drain channels (ie. Daltofterenden) and restored streams (i.e. Fraugde Baek), thus the deviation is not specific for certain stream types. Regarding the effect of the deviation of the drone method compared to the standard method on the final classification of the ecological state of the stream, station 2 and 3 at Humbaek are estimated higher using the drone method. As the objective for Humbaek is B1 this changes the classification from Not Acceptable to Acceptable.

To compare how well the specific parameters of the DFI analysis were estimated by the drone method compared to the standard method, we calculated the percentage where the drone value was exactly the same as the standard method value for the for each parameter. To show how well the two methods were matched when allowing for a difference of +/- 1 in the parameter score and thus for which parameters the drone method showed the highest proficiency a comparison of these were also made (Figure 3). Both calculations were performed on the scale parameter-value, i.e. before multiplication by the factor.

Figure 3 near here

The results show that there is a high percentage of match between the methods when estimating other physical variation, stream velocity and substrate type when the substrate consists of gravel (all above 80 % match). Parameters with a lower percentage of match are emergent vegetation coverage and substrate type when the substrate consists of sand or mud/sludge (all below 25 % match). In general, 10 of the 17 parameters had a match of 50 % or higher. It should be noted that no ochre load was seen but that the match between the two methods is still considered as absence of ochre pollution. When allowing the parameter score to deviate +/- 1 only the substrate parameters sand and mud/sludge coverage range below a 50 % match thus 15 of 17 parameters had a match of 50 % or higher.

Regarding the uncertainty of parameter recognition using the drone-based method, it was evident that directly measurable parameters such as degree of meandration, width variation or emergent vegetation coverage showed a lower uncertainty (0-25 %) than parameters such as substrate type, roots in the stream or low hanging vegetation (25-75 % uncertainty) along with undercut brinks (75-100 % uncertainty).

Table 2 near here

Discussion

Overall, the comparison between the standard method of assessment of the physical state of streams and the proposed drone-based method showed that this new method is a valid alternative in open streams. With an R^2-value of 0.76 and a P-value < 0.001 the comparison showed a significant relationship with only a few single stations having a difference in DFI of more than 8. It is important to bear in mind that any (or some) variation might have been due to inter-surveyor variability as it has been described for the surveyors using the standard-method alone with variations in DFI between 7 and 12 [18]. In this study the manual and drone-based DFI assessment was performed by different surveyors to avoid any bias in the calculation of DFI values, thus some inter-surveyor variability was a risk.

A varying DFI-score might have implications for the final classification of a stream thus the variability between both methods and surveyors should be minimized. In this study only two streams were in risk of being classified in different quality-classes due to variability between methods: Daltofterenden scored a mean DFI of 3 using the standard method and -1.7 using the drone-based method. This means that the quality-class is either *Bad* or *Poor* depending on the method [33]. As the score generally is low it does not have implications for the overall management of the stream and the resulting classification would be *Bad* as the two classes overlap [33]. Regarding Humbaek the mean DFI score was 24 using the standard method and 27 using the drone-based method. This means that the quality-class is either *Moderate* or *Good* depending on the method. This has more implications regarding management of the stream as *Good* status is the objective. Due to overlap between the quality-classes this stream would then be classified as having *Moderate* status. In general, no patterns of variation between the methods coupled to stream type were observed as both channelized and natural streams showed deviations in DFI in some stations.

When comparing the score of individual stream parameters between methods it was evident that only the parameters for sand and mud/sludge coverage and emergent vegetation were below a 25 % match between methods thus either being the most difficult parameters to assess using drone imagery or the parameters with the highest inter-surveyor variability. In this study the variation of substrate parameter scores was assessed to be due to turbidity or algae cover which in these cases cannot be abated using the drone-method. The estimation of emergent vegetation cover is on the other hand assessed to be due to inter-surveyor variability as this parameter in most cases could be directly measured in the drone imagery. When allowing for the stream parameter scale-score to vary +/- 1 when comparing the methods, it was apparent that most parameters were quite closely scored using the different methods with 15 of 17 parameters scoring above 50 % match and 11 scoring above 80 % match. These results further support that the two methods are quite equally matched when taking inter-surveyor variability into account and that the lower match for substrate-type has a small effect on the final DFI scoring.

Remote sensing of surface water flow has been tried with success in earlier studies [40, 41] but even without an elaborate experimental setup it was possible to assess the flow by filming for 10-20 seconds from 2-5 meters altitude. This approach mimics the standard-method for flow-assessment [11] as the drone merely replaces the surveyor. With a match between methods of 81 % (100 % adjusted) this method for flow-assessment is evaluated as being sufficient in the current DFI methodology.

Other studies have concluded that low-altitude mapping using drones is a feasible solution for vegetation mapping in streams [24, 42] using visual and/or NIR-bands for classification. Regarding vegetation mapping the collected data indicate that the coverage estimation of submersed and emergent vegetation is underestimated using the standard DFI method. This supports that using the drone derived maps for direct measurement of degree coverage could be more feasible. Alternatively, the collected drone data might serve as a training tool for field based, visual estimations of vegetation, width and the stream course, i.e. to calibrate the surveyor-data collected manually. In the future we will most likely see an automatization of the classification procedure using an object-based segmentation and classification approach and machine learning [29]. Both this and tests of a Convoluted Neural Network (CNN) approach for specification of image-elements also show promises especially regarding mapping of stream-near vegetation, invasive species and class of catchment area (unpub. data).

The drone-based method was especially efficient in large-scale mapping both regarding time-use and physical labor being able to map areas of more than 100x500 m size in less than 20 minutes from one access point. This both means that extended parts of the catchment area are covered with no extra cost and that stream stretches much larger than the 3x300m stations can be covered in the same time as if the standard method was used. An aspect of this is of course the time-consumption of the following analysis of data but with training and setup of a suitable workflow this is not assessed as being an issue. An additional gain by using remote sensing is the possibility of saving the image-date for future use. This have a high value as historical data is key in decision-making but also when restoring a stream or stream-near area.

The method was also efficient when extracting measurable entities such as meandration, stream width or width of unaffected stream-near area, as these could be measured directly instead of estimated in situ. Using a multirotor drone-platform it was possible to obtain images with a variable spatial resolution which makes drone-based ground truthing and validation of image objects possible. This was especially important when classifying emergent and submersed vegetation along with sediment composition.

Extracting support-data using drone-based imagery has shown great potential regarding morphological changes based on DEMs [43], bathymetry [23], and general structure classification [44]. In this study the focus point is the stream-body itself along with the stream-near area which have shown possible to map in detail. There is though a need for developing a complete workflow integrating information from near infra-red bands, thermal imagery, elevation, vegetation hot-spots and catchment area as one single drone-flight will be enough to gather immense amounts of data in this regard. A way of achieving this could be by creating a stream index that includes more of these supporting parameters. Studies show that the stream-near area also can have a direct impact on the ecological quality of an area [32] thus including more detailed information about the stream-near conditions might have a relevance in future monitoring. Including more measures such as temperature, pH, BOD, total phosphorus etc. [45] studied by drone-based physical sampling [46] or by sensors and neural networks [47] could also be implemented in a complete setup.

Even though [44] in 2018 have shown that turbidity can be quantified using drones, this requires a NIR-sensor and is only relevant for our study in assessing the limit for recognition of submersed vegetation, structures and sediment composition. The turbidity is also a limiting factor for the standard method for assessment of the physical state of streams thus this factor is not found to be specifically limiting the drone-method.

The drone-method cannot be applied in areas with a high degree of tree canopy shadowing and the results indicate that estimation of parameters such as substrate type and submersed vegetation can be impacted by emergent vegetation, surface reflection or turbidity. These conditions might not impact the end-result as with the larger areal coverage using the drone method it is possible to place the measurement stations where most of the parameters can be fulfilled or monitored. The proportion of non-shadowed streams in Denmark and the EU is not known but as large percentage is used for draining farmland it can be assumed that drone-monitoring of these is feasible. As these streams are also often of the poorest ecological quality, they are most relevant to monitor and restore. Around 80 % of all rivers in the EU are characterized as smaller rivers or streams with 75 % having widths below 2.5 m in Denmark and 80 % below 5 meters in Slovenia as examples [48]. The method is thus generally applicable where shadowing is low and stream size limited or it can readily be adjusted to cope with more elaborate systems.

The standard method for estimating Danish Physical Index has been evaluated as being quite robust even though the single parameter estimations are somewhat subjective [31], but it has also been suggested to include a more specific characterization of the stream-near area, stream-level compared to the terrain and not least shadowing by herbs, trees and bushes [31], all of which the drone-method would be suitable for estimating. As the drone-method is efficient at large scale mapping along with providing data for analyzing physical structures, vegetation mosaics, stream near area type, site details and more, the method is evaluated as being suitable for use with other European indices like the British River Habitat Survey [16, 17] if adjusted appropriately.

Conclusions

In this study a new strong method for determining the physical state of open streams was presented. The proposed method produces results which are comparable to the traditional method and is a valid technique for either supporting or in some places replacing the latter. Stream monitoring using drones show advantages in both accessing the stream and stream-near area, in mapping large areas relatively fast, and for direct geographical measurements of certain stream parameters. The weak points of the method are in most cases comparable to the issues that the manual surveyors encounter, especially concerning algae or turbidity covering the streambed.

Digital Elevation Models (DEMs) for watershed analysis, detailed catchment area maps, estimation of coverage of invasive species, drain-pipe mapping, growth hotspot detection, intelligent vegetation cutting, pollution, and more are possible measures to include using the same data-basis as collected in this study. This means that a larger data foundation is accessible for decision-makers and the lower time-use along with relatively low preliminary expenses make the method relevant for municipalities and other stream and river administrators.

Coordinates of the monitored streams:

Humbaek: Zone 32U, 567279.36 m E; 6083822.49 m N, Vibaek: Zone 32U, 562486.11 m E; 6085227.77 m N, H35: Zone 32U, 559007.34 m E; 6084452.75 m N, Seden Baek: Zone 32U, 591906.40 m E; 6144116.69 m N, Daltofterenden: Zone 32U, 594280.41 m E; 6144342.22 m N, Fraugde Baek: Zone 32U, 596049.89 m E; 6135509.67 m N, Stream Tude: Zone 32U, 651392.94 m E; 6150458.74 m N.

Acknowledgements:

The authors thank Odense and Sonderborg Municipalities for their collaboration on data-collection, access to areas and assistance in conducting this study, especially Ronnie S. Olsen from Sonderborg Municipality. We also thank the assistant Jonas Beck Pedersen for his support and assistance in data-collection. The work was carried out by support through a grant from the University of Southern Denmark covering the Strategic Focus Areas (project number: 95-306-36024) in which development of drone-methodologies is a part along with a grant from Energy Funen A/S (project number: 95-306-73151) specified for development of drone-solutions in the environmental sector. Geo Fyn A/S supplemented the project with equipment for testing.

The data that support the findings of this study are available from the corresponding author upon reasonable request. Fig 1 was created in Microsoft Powerpoint 2016 and Fig 2 and 3 was created using Sigma Plot 12.0.

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Tables

Table 1 Mean characteristics of the 7 studied streams including environmental objectives and most recent classification of condition. The last calculated DFI value is shown with year of monitoring and placement of the station compared to this study – upstream (US) or downstream (DS). The parameter ‘Level of difficulty’ describes how easy the stream was mapped using the drone-method relating to turbidity, overgrowth etc. NA indicates that no information was available.

Stream	FRA	SED	DAL	TUD	HUM	VIB	H35
Region in Denmark	Funen	Funen	Funen	Sealand	Southern Jutland	Southern Jutland	Southern Jutland
Objective	Good	NA	NA	Good/B_2	Good/B_1	NA /B_1	Good/B_1
Condition (most recent)	Moderate	NA	NA	Bad	Moderate	NA	Bad
Last calculated DFI value	27 (2013)	4 (2010)	0 (2010)	42 (2008, DS)	32 (2012)	33 (2015, DS) -4 (2011, US)	37 (2015)
Size (width) [m]	1.5 – 2.5	0.3 – 0.7	0.8 – 1.9	2.5 – 3.5	0.5 – 0.9	1.4 – 2.3	1.0 – 1.5
Direction of flow	SW to NE	N/A	SW to NE	N to SW	W to E	N to S	N to S
Flow velocity	Semi-fast	Still	Still	Slow	Semi-fast	Still to slow	Slow
Cross section	Natural	Channelized	Semi-natural	Semi-natural	Natural	Semi-natural	Semi-natural/natural
Near-stream land use	Grazed, gardens	Grazed, nature	Agriciulture, grazed	Agriculture, gardens	Agriculture	Agriculture, nature	Nature
Length of mapped section [m]	918	379	560	1,262	305	676	478
Level of difficulty in mapping	Very Easy	Very hard	Easy	Easy	Medium	Easy	Easy

Table 2 Parameters that are described, estimated and valued in the traditional manual method (Wiberg-Larsen and Kronvang, 2016) along the relative uncertainty of parameter recognition in ranges from 0-25 % (low uncertainty) to 75-100% (high uncertainty) determined by two experienced biologists.

Parameters	**Uncertainty**	**Parameters**	**Uncertainty**
Riffles and pools	50-75 %	Emergent vegetation (after postprocessing)	0-25 %
Degree of meandration (after postprocessing)	0-25 %	Submersed vegetation (after postprocessing)	25-50 %
Cross section profile	25-50 %	Other physical variation	25-50 %
Width variation (after postprocessing)	0-25 %	Ocre load	NA – not observed
Undercut brinks	75-100 %	Stone coverage	25-50 %
Width of unaffected stream-near area (after post processing)	0-25 %	Gravel coverage	25-50 %
Low hanging vegetation	50-75 %	Sand coverage	50-75 %
High energy velocity	25-50 %	Mud/sludge coverage	50-75 %
Roots in the stream	25-50 %		

Figure 1:

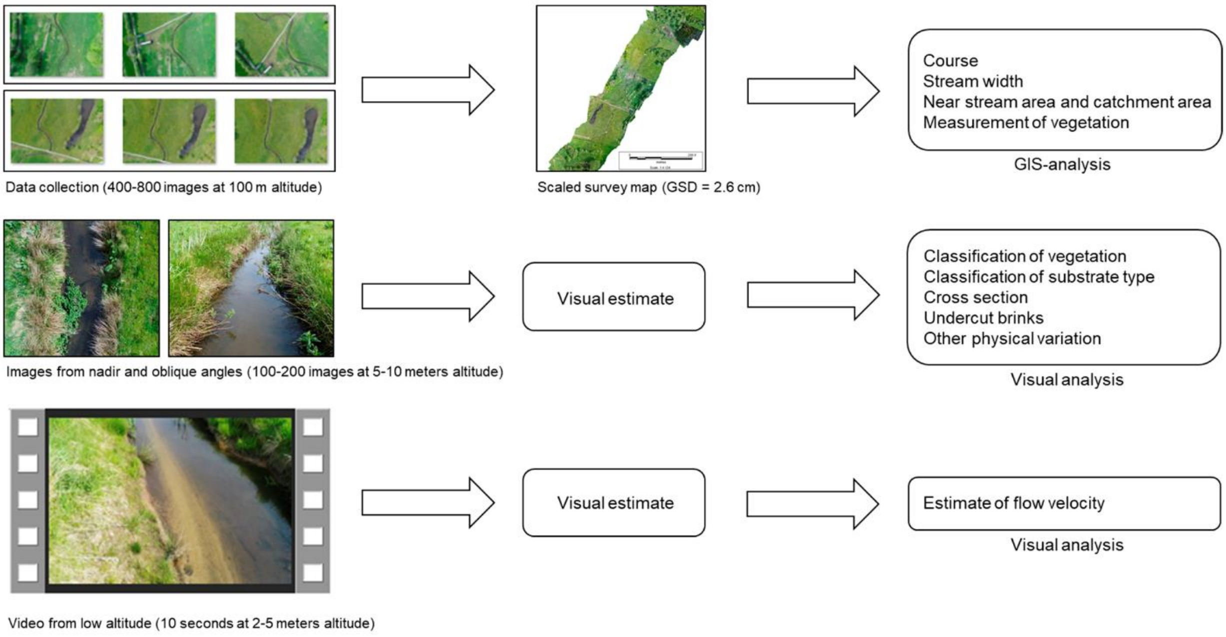

Figure 2:

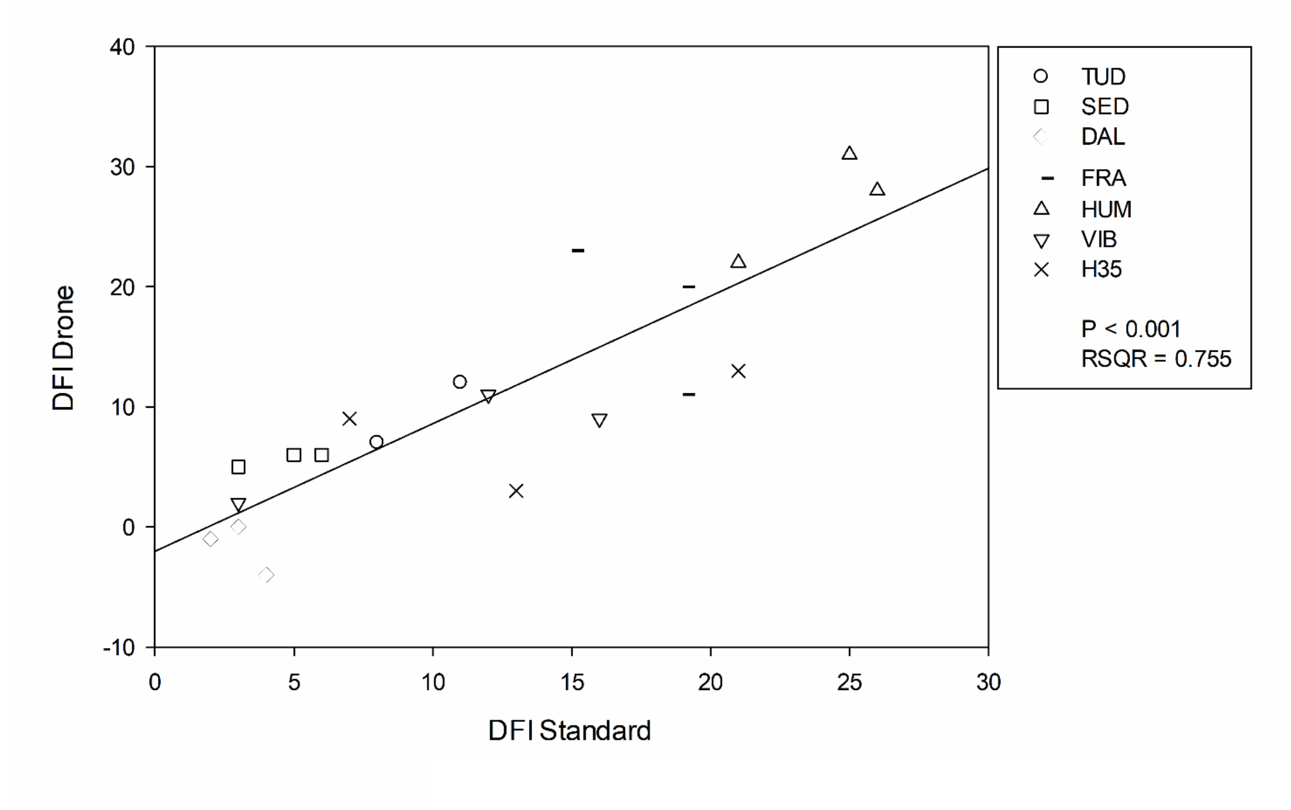
DFI Drone
40
30
20
10
0
-10
0
5
10
15
20
25
30
DFI Standard
TUD
SED
DAL
FRA
HUM
VIB
H35
P < 0.001
RSQR = 0.755

Figure 3:

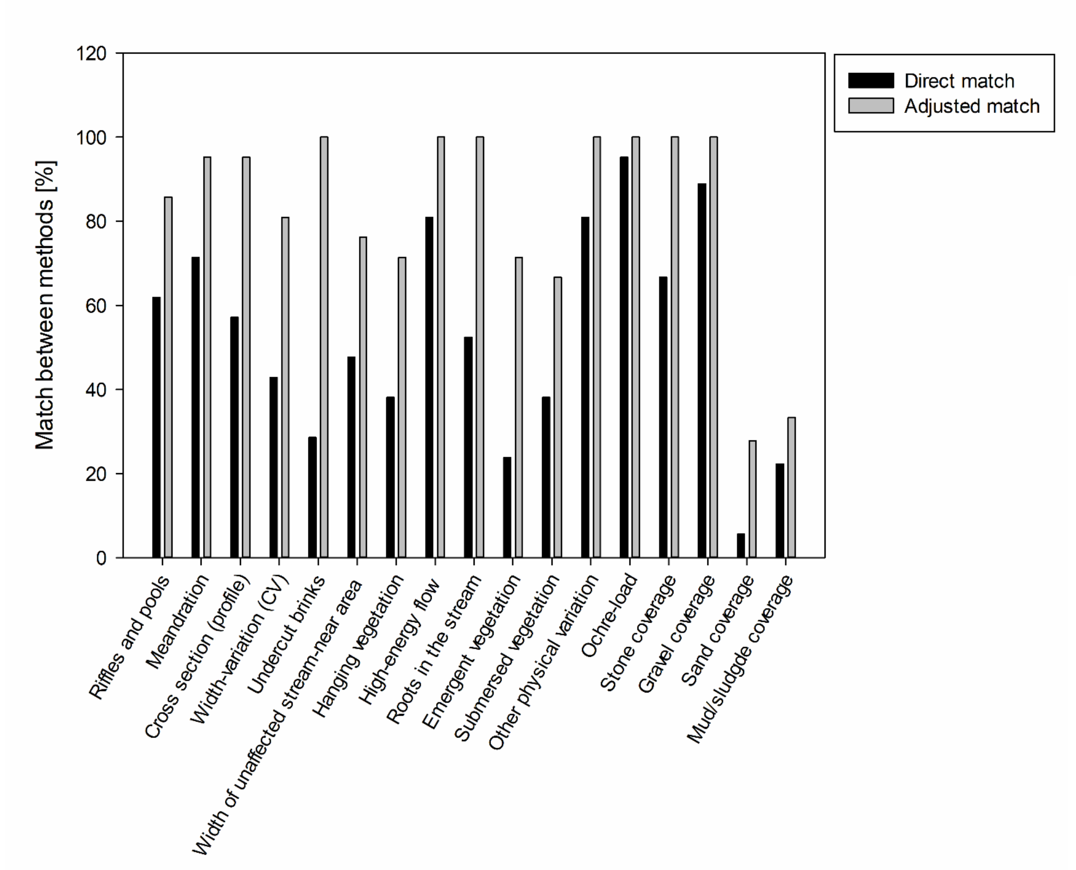
Match between methods [%]
120
100
80
60
40
20
0
Direct match
Adjusted match
Riffles and pools
Meandration
Cross section (profile)
Width-variation (CV)
Undercut brinks
Width of unaffected stream-near area
Hanging vegetation
High-energy flow
Roots in the stream
Emergent vegetation
Submersed vegetation
Other physical variation
Ochre-load
Stone coverage
Gravel coverage
Sand coverage
Mud/sludge coverage

Figure legends

Fig. 1 Conceptual diagram of the methodological workflow from in-situ flight to analysis

Fig. 2 The relationship between standard DFI (x-axis) and drone-based DFI (y-axis), n=21

Fig. 3 The percentage (%) where there was a direct match between the scale-values obtained by the two different methods (black bars). The percentage (%) where the scale-value only differed +/- 1 between the two different methods (grey bars) represented by an adjusted match

Figure 1 should be color printed for publishing.