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Exploring the Utility of Small Unmanned Aerial System (sUAS) Products in Remote Visual Stream Ecological Assessment

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Title:

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Running Head:

sUAS for Stream Ecological Assessment

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Author Contributions:

AE, KG, SG conceived and designed the research. AE was the FAA Part 107 remote pilot who conducted the sUAS flights and produced all data products. BP conceived and ran the in-field scoring campaign. AE and KG interpreted data and drafted manuscript. SG and BP provided comments and edits.

Abstract:

Many restoration projects' success is not evaluated (Roni & Beechie 2013; Nilsson et al. 2016), despite available conventional ecological assessment methods. There is a need for more flexible, affordable, and efficient methods for evaluation, particularly those that take advantage of new remote sensing and geospatial technologies (Hubbart et al. 2017). This study explores the use of illustrative small unmanned aerial system (sUAS) products, made using a simple structure-from-motion photogrammetry workflow, coupled with a visual assessment protocol as a remote evaluation and ecological condition archive approach. Three streams were assessed in the field ("surface assessments") using the Stream Visual Assessment Protocol Version 2 (SVAP2) and later illustrated in sUAS products. A survey of 10 stream experts was conducted to 1) assess the general utility of the sUAS products (high resolution video, orthomosaics, and 3D models), and 2) test whether the experts could interpret the products and apply the 16 SVAP2 elements remotely. The channel condition, bank condition, riparian area quantity, and canopy cover elements were deemed appropriate for remote assessment, while the riparian area quality, water appearance, fish habitat complexity, and aquatic invertebrate complexity elements were deemed appropriate for remote assessment but with some potential limitations due to the quality of the products and varying site conditions. In general, the survey participants agreed that the illustrative products would be useful in stream ecological assessment and restoration evaluation. Although not a replacement for more quantitative surface assessments when required, this remote visual approach is suitable when more general monitoring is satisfactory.

Key Words:

3D Model, Drones, Evaluation, Illustrative, Orthomosaic, River Restoration, Survey, Video

Implications for Practice:

- Information about the ecological condition of rivers can be extracted remotely and rapidly from sUAS products using a visual assessment protocol. This more flexible, qualitative approach fulfills a methodology niche for practitioners interested in using sUAS but do not need or have the resources to create survey-grade sUAS products.
- This approach provides a simple and effective way to collaborate with remote partners and reduce in-field subjectivity. It provides a level of remote assessment between surface assessments ("boots-on-the-ground") and low-altitude manned aircraft flyovers.
- sUAS products provide an illustrative record of site conditions for archival purposes, providing a more holistic perspective than conventional field photographs. In addition, the expression of stream planform geometry (sinuosity, radius-of-curvature and amplitude) is enhanced.

Main Text:

<u>Introduction</u>

Current Restoration Monitoring and Evaluation

It is widely recognized that restoration projects are often completed without sufficient post-project evaluation (Bernhardt et al. 2005; Roni & Beechie 2013; Nilsson et al. 2016). Common reasons for neglecting monitoring and evaluation of a restoration project stem from inadequate funding, technical, and administrative issues related to monitoring framework design and difficulty in selecting an assessment protocol (Roni & Beechie 2013). Without post-restoration evaluation, a project's success cannot be determined, and the broad field of river restoration does not advance from lessons learned. Opportunity is lost to gain insight into restoration processes to inform future projects, gain public acceptance, and further restoration science. This is an openly acknowledged problem in the restoration literature (Bradshaw 1993; Hobbs & Norton 1996; Hobbs & Harris 2001; Woolsey et al. 2007; Roni & Beechie 2013; Morandi et al. 2014; Nilsson et al. 2016).

There are a variety of ecological assessment protocols to choose from depending on a project's needs. On one hand, qualitative visual-based assessment protocols are rapid and easy to implement, providing a holistic picture of a site's conditions. They often take the form of quality indices, consisting of scored variables that produce a single representative score. However, these protocols are not often used due to their subjectivity and questionable repeatability. On the other hand, there are more sophisticated, quantitative assessments involving field measurements that offer greater objectivity and repeatability at the cost of greater resources like time, expertise, and financial expense (Somerville & Pruitt 2004). Despite having these tried-and-true methods, project monitoring and evaluation are often foregone. There is a need for more affordable and rapid assessment approaches in river restoration, particularly those that take advantage of new remote sensing and geospatial technologies (Hubbart et al. 2017).

Visual assessment protocols are useful when there are time constraints, a small budget for monitoring, or other obstacles that would impede a quantitative approach from being feasible. They have been successfully used in restoration and ecological evaluation studies (Zogaris et al. 2009; Djordjevic et al. 2017). The United States Army Corps of Engineers (USACE) is interested in using the Stream Visual Assessment Protocol Version 2 (SVAP2) in their stream restoration monitoring programs, particularly if the assessor subjectivity can be reduced to make the assessment more reliably repeatable (B. Pruitt 2019, US Army Engineer Research and Development Center, personal communication).

Modernizing Restoration Monitoring and Evaluation

Emerging technologies are allowing us to expand the restoration evaluation toolbox and experiment with developing methodologies that are more flexible and efficient than conventional approaches. Much research has focused on small unmanned aerial systems (sUAS) and remote sensing techniques. Methods are being developed to quantify and map geomorphic changes following river restoration (Marteau et al. 2017), vegetation structure and species (Michez et al. 2016; Hortobágyi et al. 2017; Koch et al. 2017), substrate (Woodget & Austrums 2017), physical habitat conditions (Casado et al. 2015), to monitor water quality parameters like turbidity (Vogt & Vogt 2016; Ehmann et al. 2019), and to acquire accurate stream bathymetry (Woodget et al. 2015; Partama et al. 2017; Dietrich 2017).

The illustrative nature of sUAS imagery lends to its application in ecological evaluation, particularly when viewed from the perspective of visual assessments. The photographs and video footage collected via sUAS can be viewed directly, or they can be processed using structure-from-motion (SfM) photogrammetry to produce additional sUAS products, including 3D models and orthomosaics. These high-resolution products provide a level of detail that is unmatched by currently-available satellite imagery.

Researchers have found that manual interpretation can be a viable solution for mapping ecologically-significant characteristics throughout a site when limited spectral resolution inhibits classification methods; for example, manually mapping invasive vegetation in an RGB sUAS orthomosaic vs. using a classification approach (Hill et al. 2016). Others have found manual interpretation to be a straightforward solution for mapping features throughout orthomosaics like bar formations (Rusnák et al. 2018), patches of vegetation types (Räpple et al. 2017), and other habitat conditions (Tamminga et al. 2015; Woodget et al. 2017). Helicopter video footage has been used to evaluate the ecological condition of stream segments and watersheds, demonstrating how manual interpretation can provide a multiscale approach and how such video documentation provides the ability to revisit assessments without additional fieldwork (Pruitt et al. 2017). Given the success of manual interpretation, sUAS products could serve as a record of site conditions useful for communicating and illustrating restoration outcomes. Site photographs are important to demonstrate project success and are easily understood by project sponsors and the general public alike (Roni & Beechie 2013). The perspective provided by sUAS builds upon conventional photographs and is enhanced by low-altitude video, enabling the general public to visualize stream corridor conditions (Pruitt et al. 2017).

Since visual assessments primarily use metrics that do not require physical interaction with a site, these metrics should be possible to assess remotely using the sUAS products. This can engage multiple remote assessors, reducing the subjectivity of visual assessments. This approach of manually interpreting the products provides a simple alternative to more technically intensive, but quantitative, GIS analysis that uses highly geospatially accurate sUAS products. For example, surveying ground control points (GCPs; e.g. Marteau et al. 2017) or a more expensive, sophisticated sUAS (e.g. Tomaštík et al. 2019) is typically required in SfM workflows to produce highly accurate products.

Collecting sUAS imagery requires little time out in the field and minimizes impact to a site. Consumer-grade sUAS are affordable, especially compared to airplane or helicopter photography, making aerial assessments accessible to practitioners on a budget. Certified commercial remote pilots provide practitioners the option of hiring a pilot to collect imagery, enabling a practitioner to outsource if they do not have an in-house pilot. Although not an appropriate replacement for quantitative surface measurements when required, this proposed visual approach is suitable for sites where more general monitoring is satisfactory. It can also serve to augment more quantitative remote sensing approaches.

Study Goals

This study explores a multipurpose solution to the challenges associated with visual ecological assessments: using sUAS to produce illustrative products of streams that can be evaluated remotely by experts using visual metrics. We answer the question, "What can be gained from manually interpreting products from the simplest of sUAS workflows?" The proposed sUAS workflow makes some benefits of this emerging technology accessible to practitioners who do not have access to survey equipment or more expensive sUAS, the technical expertise to analyze the products in GIS and other geospatial software, or those who do not need the level of quantified information acquired from more sophisticated workflows but would benefit from the illustrative products. This work helps determine the flexibility of sUAS technology to suit the needs and resources of projects and stakeholders.

Methods

USACE Stream Tour

The USACE conducted a stream tour in the summer of 2017. The tour tested the SVAP2 for regulatory use, e.g. compensatory mitigation, across a variety of streams throughout New England. The SVAP2 is a visual ecological assessment protocol that consists of 16 scoring elements, covering a wide range of ecologically-significant site characteristics. These scores are assessed on a scale of zero to 10, with 10 indicating ideal ecological conditions. Details of the scoring criteria can be found in the United States Department of Agriculture National Biology Handbook, Subpart B, Part 614 (2004). A core interdisciplinary team of four USACE professionals conducted the assessments.

Selected Sites

Three of the streams assessed by the USACE were revisited for sUAS imagery collection (Fig. 1). These sites were chosen due to their diversity in site characteristics (e.g. turbidity of water, channel condition, restoration project types). The sensor on the sUAS was a consumer-grade RGB camera and terrain beneath tree canopy could not be seen. Therefore, USACE sites with minimal canopy cover were selected for this study. The first reach is located on Town Brook in Plymouth, MA (3D model, orthomosaic). The second reach is located on East Branch Piscataqua River in Falmouth, ME (3D model, orthomosaic). The third reach is located on West Branch Deerfield River in Readsboro, VT (3D model, orthomosaic).

sUAS Product Creation

sUAS flights were planned for each of the selected sites. Flight paths were set to collect 4K video as a DJI Phantom 3 Professional sUAS completed its route at a constant speed and altitude.

Both nadir and slightly off-nadir footage were collected with automated flight paths, and freeform video was collected to create illustrative video of each reach. Prior to executing the flights, GCPs were placed and surveyed using a Topcon Hiper Lite plus. The survey equipment malfunctioned at the VT site, therefore scale was added in SfM to the sUAS products by using the known size of a GCP. GOM Player was used to extract timed interval stills from the videos with enough image overlap for SfM. These stills were fed into Agisoft PhotoScan Professional, SfM software, to create the orthomosaics and 3D models. GNU Image Manipulation Program 2 was used to annotate the orthomosaics. 3D models were published and annotated on sketchfab. iMovie video editor was used to make the video published on YouTube (video). This general sUAS workflow can be used at other sites and adapted to suit project needs (Fig. 2). Processing details in PhotoScan (Document S1) and site-specific details (Table S1) can be found in the supporting information.

Survey and Participants

We tested the ability of stream experts to remotely assess reaches using sUAS products and visual assessment criteria (SVAP2) to determine the products' utility in stream ecological evaluation. To do so, a survey (Document S2) was sent to remote assessors. This survey contained links to the products available online as well as a variety of questions covering the SVAP2 remote assessment exercise and narrative questions about the remote approach. Stream experts were provided three types of sUAS products to manually interpret: orthomosaics, video, and 3D models. Remote SVAP2 scores and reasonings for those scores were compared to the in-field scores to understand which scores worked remotely for certain types of stream environments. We were also able to see which scoring elements tended to be over- or underestimated by the remote assessment approach. Narrative responses and score rationale from the participants provided rich information regarding the feasibility, practicality, and desirability of the remote assessment approach.

A total of ten stream experts participated in the survey. Three of these experts were from the USACE team that conducted the stream tour. Out of the seven participants who were not part of the USACE team, three were from other government organizations, two were from non-profits, and two were from academia. Some participants reported mixed backgrounds, such as working in consulting prior to their current role.

Nine participants reported their self-assessed expertise on a scale of 0 to 5, with a score of 5 representing a high level of expertise. In general, there is a relative gap in macroinvertebrates and fisheries expertise in the participant pool (Fig. 3). Participants reported additional areas of expertise, including GIS and LiDAR, dam removal planning and facilitation, stream crossing assessment, and creating ecological assessment protocols. Out of the ten participants, four had experience with the SVAP2 prior to completing the survey. Out of the ten participants, six reported having experience with other visual assessment protocols. One participant had no experience with visual assessments.

Results

Narrative Survey Responses

The narrative survey responses were key in determining the sUAS product utility according to the stream experts. When we asked "Do you think having imagery and models such as these is useful for regulatory stream monitoring purposes? How about in the context of general restoration efforts?", most survey participants reported that the imagery and models would be useful for regulatory stream monitoring purposes and restoration efforts (Fig. 4). Out of the nine respondents, five participants agreed that the products would be useful (“Useful”). For example, one participant wrote: “I found the [sUAS] products to be very useful to assess condition. I would think these tools could be used to assess stream condition and monitor changes over time in different study reaches.” Three of these nine participants acknowledged the usefulness of the products for these applications, but mentioned limitations (“Useful, but…”). One participant acknowledged difficulty seeing the streambed in some products. Another responded that regulatory monitoring is often based on water quality, so in-field quantitative measurements would be more effective in these cases. The third participant stated that sUAS would certainly have value for regulatory monitoring purposes, but “because of the nature of what regulatory agencies are, [sUAS] use by the agencies themselves for regulation will not be occurring for the foreseeable future.” One participant responded with “maybe” for this question, and their reasoning related to the SVAP2 metrics rather than the utility of the sUAS products. Based on these responses, we conclude that the illustrative aspects of sUAS products are useful for restoration evaluation and worth exploring further.

When asked, “Were certain elements easier to score from the 3D model or orthomosaic? If so, which ones and why?” respondents identified elements associated with riparian vegetation, channel condition, and bank condition as relatively easy to assess using the sUAS products. On the other hand, they identified hydrologic alteration, aquatic invertebrate community, riffle embeddedness, and salinity as elements that could not be assessed using the products. Assessors criticized the ME site products specifically, reporting that they did not have satisfactory resolution and that there were natural limitations to visibility in this reach (e.g. water turbidity). Multiple respondents wrote that although there is not enough information in the products to complete all the scoring elements, the details were satisfactory for the feasible elements.

The orthomosaics were helpful for all feasible scoring elements, while the 3D models were reported to be especially useful for examining channel condition, entrenchment, bank features, and relative vegetation height (Fig. 5). Most of the participants cited the orthomosaics or 3D models as the most useful products for remote evaluation, and one participant preferred the video. The video gave participants the ability to observe water flow, as well as get a better sense of water clarity and depth. The usefulness of the 3D model was questioned by a couple participants, one who criticized that the models did not give enough sense of slope for it to matter, and another who did not use the 3D models as much due to difficulty navigating them. On the other hand, another participant preferred using the 3D models because of the ability to navigate them and enhance the view of the channel banks. One participant expressed that the orthomosaics “seem to show better detail/resolution”, which may make them more suitable for assessing certain elements over the other products. Which sUAS product a respondent found most useful came down to which element was being assessed, personal preferences, and ability to navigate potentially unfamiliar online platforms.

We asked participants “Are there other uses for this type of data and information that are beyond this type of ecological stream assessment?” many participants responded with ideas to use sUAS data and visualizations in other applications, with one participant suggesting mitigation monitoring reports. Multiple participants said the data would be useful for long term monitoring and assessing change. Participants specifically mentioned monitoring changes in surface water extent, channel morphology, and shifts in vegetation community. One participant theorized that the sUAS products would be useful in monitoring areas that are difficult to access on foot, like monitoring disturbance or encroachment. Other applications included determining width vs. drainage area or flow relationships, bank height, and floodplain connectedness, as well as monitoring wild ungulates migration, bird migratory patterns, and shoreline erosion.

When asked how the remote assessment compared to being out in the field, the respondents expressed that while the remote approach would be useful, it is no replacement for fieldwork. Too many limitations exist regarding the data that can be obtained from the sUAS products compared to information that can be gathered in the field. However, one participant reported that the "imagery provided the ability to get the overall broader feel for a site and enable mental reconstruction of river processes occurring at a site, and in a quicker manner than would be experienced in the field [...]". Another participant suggested that combining both approaches would likely yield better results. We agree, as the tested remote approach was meant to supplement fieldwork for better use of visual protocols.

Survey participants provided many different ideas to improve remote assessment. Multiple participants reported that they wanted more spatial information like channel width, bank height, and wave-length measurements annotated on the models rather than relying on GCPs for scale and asked for a measurement tool they could use on the orthomosaics and 3D models. A point-to-point measurement tool for distance, a polygonal tool to measure surface area, and a volume measurement tool for the 3D models are possible to include in a sUAS product viewing platform. Such tools would provide more quantitative information than the data collected for the in-field SVAP2 assessment. Other respondents suggested that the SVAP2 metrics could be changed to something more meaningful for low-altitude visual assessments, like considering natural planform patterns, channelization, and straightening for hydrologic alteration. It was also recommended that the sUAS products cover a larger area relative to the reach, especially when the reach is next to a road to see how the road may impact the stream. Participants suggested including additional remote sensing data. One participant recommended adding “more cool, yet expensive stuff” like LiDAR, thermal mapping, and hyper-spectral imagery. These types of data could be useful, but their inclusion is limited by the resources available to the agency creating the products.

Many participants recommended types of contextual information that should be provided alongside the sUAS products. In general, the participants wanted better geographic, spatial, topographic, and hydrologic context for the reaches that was not provided in the remote assessment and would not be readily available from the in-field assessment. Specific requested information included: (1) watershed scale information such as land use/cover and topography, (2) hydrologic information like flow regime, (3) site history, and (4) stream order and bifurcation ratio. Including a preliminary watershed assessment for each reach would have provided context for the assessors. Based on these responses, we recommend the inclusion of such summaries alongside sUAS products to aid in their interpretation. These suggestions would improve not only the remote assessment approach but enhance the application of the SVAP2, as this level of quantitative and contextual information is typically not gathered in the field.

Comparing Numerical Scores

It was insightful to see how the remote assessment scores reported by the participants (“remote scores”) compared to the scores from the assessment performed in the field (“in-field scores”). The remote and in-field scores were first compared according to their overall SVAP2 scores (Fig. 6a). This is the overall score assigned to a reach that reflects its general ecological condition, considering all the applicable SVAP2 scoring elements for a reach. One set of in-field scores for each reach was provided by the USACE that was agreed upon by the in-field team. The remote scores represent the overall scores calculated from each survey participants’ SVAP2 scores for each site. In general, the sites located in MA and ME had good agreement between the in-field score and remote scores. The site in VT was evaluated to be in poorer ecological condition by the remote assessors than by the USACE team.

In general, if a participant had visited the site in person prior to conducting the remote assessment, their remote score was closer to the in-field score than those of participants who had not visited the site (Fig. 6b). The overall SVAP2 remote scores were significantly closer (smaller absolute difference) to the overall SVAP2 in-field scores if the survey participant had visited the site prior to completing the survey (Student's *t*-test, $\alpha = 0.05$, $p = 0.0036$). However, all the participants who had visited the sites before, except one for the ME site, were part of the USACE team that conducted the in-field assessments. None of the other reported nominal experience parameters showed significantly closer overall remote scores (smaller absolute differences) to the overall SVAP2 in-field scores, including prior experience with the SVAP2.

Differences in site characteristics and sUAS product quality impacted the feasibility of remote assessment and contributed to the observed discrepancies between the remote and in-field scores. To determine specific characteristics, the differences in the remote and in-field scores were examined across the scoring elements that make up each site's overall SVAP2 score (Fig. 7). The elements were organized into four categories based on their feasibility to be evaluated using the remote approach: (red) infeasible and not recommended for remote assessment, (orange) some scoring metrics possible for remote assessment, (yellow) feasible for remote assessment but with limitations due to the quality of sUAS products, and (green) feasible and straightforward for remote assessment.

The green category contains elements that were straightforward to evaluate using sUAS products according to the survey responses. These elements are: channel condition, bank condition, riparian area quantity, and canopy cover. The bird's eye perspective provided by the sUAS was useful to the remote assessors for evaluating riparian area quantity and canopy cover, which were elements that focused on the percent cover and spatial distribution of vegetation and canopy. Channel condition is based on the Schumm channel evolution model (Schumm et al. 1984) and the scoring criteria consider which model stage the reach is in, evidence of erosion and bank failures, presence of point bars, and connection between the channel and floodplain. Bank condition examines the presence and severity of bank failures and erosion, presence of fabricated structures on banks, protection of banks (e.g. vegetation), and recreational and/or livestock use contributing to instability. Many of these metrics were easily identifiable through the sUAS products, with survey participants noting the topographic information in the 3D model and the ability to magnify the view of the banks to be helpful. The disparity in remote and in-field scores for bank condition for the VT site mainly resulted from the different interpretations of the scoring criteria given the riprap bank stabilization project, which reflects a limitation of the SVAP2. The overestimation of bank condition at the ME site by remote assessors seems to have come from considering the steep banks and erosion against the amount of vegetation present to stabilize them, with many remote assessors leaning towards a higher score due to the vegetation. Once again, this discrepancy lies more in the subjective nature of the SVAP2 rather than the availability of information in the sUAS products.

The yellow category consists of elements feasible for remote assessment but with limitations due to quality of sUAS products. These elements were: riparian area quality, water appearance, fish habitat complexity, and aquatic invertebrate habitat. Riparian area quality is assessed in the SVAP2 based on the presence of invasive species, the density and age structure of the natural vegetation, the diversity of the natural vegetation, and the presence of concentrated flows throughout the area. Participants were successful in identifying vegetation structure aspects relevant to the scoring metrics using the sUAS products. However, some respondents provided caveats to their reasonings, such as “Not able to identify any invasives in the photos but anticipate invasives in farm field and its edges.” Another participant compared their remote experience and their in-field experience at the ME site stating, “I know from site visit there are invasives here, but I couldn’t pick them out on remote data. There are also several erosion channels across the field that might be missed due to the vegetation.” Riparian area quality was underestimated by the remote approach compared to the in-field approach for the VT site relative to the other sites, which was partially due to the trees in leaf-off condition not being captured well using SfM. Since it was common for participants to have difficulty identifying invasives with confidence, we deem this element feasible to be scored using the remote approach but may be limited due to the sUAS product quality. Including lower-altitude imagery may provide the higher resolution needed to identify invasives. The water appearance scoring element asks assessors to consider the clarity or turbidity of the water, asking to what depth submerged features are visible in the stream. This element also considers the presence of oil sheen on the surface as well as evidence of metal precipitates in the stream. Many participants reported scores for this element with straightforward reasonings, such as “Water is very clear. The entire bed of the stream in this reach can be seen.” regarding the MA site, and “murky/turbid (clay soils)” regarding the ME site. However, some participants were not as confident in their responses and reported reasonings that questioned the quality of the sUAS products. For example, multiple participants reported that it was difficult to determine depth, which impacts their ability to evaluate water appearance according to the SVAP2 metrics. Multiple participants reported that glare on the water’s surface limited their ability to assess water appearance at the ME site; they were unsure if the discoloration of the water was reflected cloud cover or turbidity. Therefore, the ability to evaluate water appearance may be limited by the quality of the products. We foresaw glare as a potential issue and equipped a polarizing filter to the camera, but its performance was not consistent due to the inability to adjust the filter during flight.

The scoring criteria for fish habitat complexity and aquatic invertebrate habitat counts the number of habitat features throughout a reach; the higher the diversity of features, the better the ecological score. Examples of counted habitat features for fish and macroinvertebrates include logs/large wood, pools, boulders, and undercut banks. Scale differentiates fish and aquatic invertebrate habitat, with invertebrate habitat features examined on a smaller scale of the reach and including smaller habitat features relevant to invertebrates, like leaf packs. The scores for both habitat elements tended to be underestimated by the remote approach relative to the in-field assessment (Fig. 7). This was due to some habitat features being difficult to see in the sUAS products. Certain features, like boulders and logs, were relatively easy to identify in the products. However, some survey participants had trouble identifying pools and undercut banks, therefore they would not be included in the remote count but included in the in-field count. Others explained that the water's turbidity and turbulence sometimes limited their ability to see in-stream habitat features. The resolution of the sUAS products was not fine enough for participants to consistently identify smaller habitat features, particularly some of those listed in the aquatic invertebrate habitat scoring element. We conclude that, although feasible, the remote approach will most likely underestimate habitat conditions relative to in-field assessments due to limitations associated with the resolution and in-stream clarity shown in sUAS products. One remedy for this would be to collect imagery at a lower altitude, providing a more detailed view of small habitat features. This would address limitations associated with resolution, but not if turbid/turbulent water is present.

The orange category has elements where only some aspects of the SVAP2 scoring criteria are possible for remote assessment; not all the SVAP2 scoring criteria were based on visual characteristics. These elements were: nutrient enrichment, barriers to aquatic species movement, and manure or human waste presence. The nutrient enrichment scoring element requires assessors to smell odors at the site to assign lower SVAP2 scores. However, most of the scoring criteria for nutrient enrichment are visual, including detecting greenish water, algal growth, and dense stands of aquatic plants, which led to a good agreement between the remote and in-field scores (Fig. 7). The “barriers to aquatic species movement” and “manure or human waste presence” categories had similar issues. Some of the scoring criteria were able to be seen in the products, such as physical barriers like dams within the reach or evidence of livestock or manure in the stream (e.g. manure piles, livestock fencing, or hoof prints). However, these scoring elements have additional criteria that would be better addressed in a watershed assessment rather than through an in-field assessment or examining sUAS products due to temporal and geographic restrictions. For example, the barrier element asks assessors to consider water withdrawals or seasonal water quality that could impact the movement of aquatic species. The manure/human waste element asks assessors to consider to what degree livestock have access to the stream. Many survey respondents provided unsure reasonings with their scores for these elements. For example, a participant noted that although no barriers were visible in the reaches used in this study, since they were in New England there was a “barrier likely within 5 miles.” The numerical comparison shows good agreement between the remote and in-field scores for the orange category elements (Fig. 7), but there was little diversity in the in-field scores for these elements.

All three sites had an in-field score of 10 for manure and human waste presence and barriers to aquatic species movement. The ME and MA sites had 5 for nutrient enrichment while the VT site had a 9, with no reaches severely impacted by nutrient enrichment. Reaches impacted by waste, barriers, and nutrients should be included in future studies to better determine whether the remote approach is effective.

The elements in the red category are not recommended for remote visual assessment, including: pools, hydrologic alteration, aquatic invertebrate community, riffle embeddedness, and salinity. Pruitt et al. (2017) found similar limitations when interpreting low-altitude helicopter video. Many of the participants expressed having difficulty in remotely detecting pools in the sUAS products, and this guess work explains the range of differences between the in-field and remote scores for this element (Fig. 7). Much of the scoring criteria for hydrologic alteration would be better addressed in a watershed assessment rather than through an in-field assessment or examining sUAS products, as much of the criteria is based on flow regime rather than visual indicators. The scoring criteria for aquatic invertebrate community and riffle embeddedness require assessors to interact with the environment to collect macroinvertebrates and pick up clasts. Some participants attempted to guess which invertebrates would inhabit the reaches and riffle embeddedness based on the visual evidence in the sUAS products, but this is not a reliable approach. Most survey participants reported that they could not assess salinity. All the participants who gave scores for salinity reported 10 across all three sites with reasonings such as “no obvious halophytes”, but we were not able to test if remote assessors would have been able to identify visual salinity impacts since all three sites received in-field salinity scores of 10.

Discussion

While we used the approach of comparing the in-field scores to the remote scores in this study, it is important to note the inherent subjectivity in the SVAP2 as a visual assessment. This subjectivity was reduced in the in-field USACE assessments by using an interdisciplinary team that agreed on one set of SVAP2 scores. However, this value should not be considered "true," but rather a good example of an in-field assessment useful to evaluate the potential limitations of assessing the same elements remotely with the sUAS products. In this case, the numeric differences between the in-field and remote scores are not as significant as the general trends they illustrate: whether the remote scores are under- or overestimating ecological condition relative to the in-field sample, the degree of variation in one element relative to other remotely-assessed elements, and themes in the reasonings and narrative feedback of the survey participants were more useful for the purpose of this study.

To illustrate another, more technical solution for the inherent subjectivity in the SVAP2, we assessed the riparian area quantity scoring element for the MA site using a remote sensing approach in GIS (Fig. 8). These values derived in GIS are considered "true" vegetation cover values relative to the scores provided from both the in-field and remote visual assessment approaches. According to the SVAP2 criteria, with a vegetation cover of 96% on one bank and 84% on the other along with the vegetated bankfull width estimates, the reach's score for riparian area quantity is 7.5 out of 10 (assumed score of nine for left bank, six for right due to vegetation gaps) using this GIS approach. The USACE gave this same reach a nine in the field for riparian area quantity, and the remote scores from the survey had a range of two to 10 with an average of 7.3. The in-field assessors overestimated the riparian area quantity relative to the GIS-derived score, while the remote assessors' average score is close to the GIS-derived score, likely due to the aerial perspective provided by the sUAS products. This demonstrates how using sUAS products and multiple remote assessors can help produce a more objective evaluation when using visual metrics. However, given the range of the visually-derived scores, using a quantitative GIS analysis provides a more objective, accurate, and repeatable method if resources are available to complete it. These quantitative metrics can redefine the scoring scale in the SVAP2; rather than trying to decide if a vegetation cover of 96% qualifies as a 10, 9, or 8, the criteria can specify percentage ranges.

Sometimes site-specific characteristics or sUAS product complications inhibited an SVAP2 element from being assessed properly. We identified some characteristics and complications through examining the survey results, and created a guide showing which characteristics can impact an elements' feasibility (Table 1). Practitioners can consult this table to help decide whether the remote approach is appropriate for their site and project goals.

Although topographic survey data was collected at two of the three sites and used to create sUAS products, this data is unnecessary for site illustration and remote visual ecological assessment. Including an object of known size in the imagery to provide a sense of scale is enough. Survey data or a more sophisticated sUAS is required for those who plan on using sUAS products for more quantitative geospatial assessments, such as those conducted in GIS with highly-accurate orthomosaics and topography models. Video footage was collected for this study rather than photographs. The workflow works with either imagery options, but by demonstrating the feasibility of the approach with video, we have shown that practitioners can use the least sophisticated sUAS to collect their imagery provided enough overlap for SfM between the video stills or photographs. If the sUAS has GPS capabilities, the workflow can be completed with flight paths that collect photographs, enabling practitioners to skip still extraction and obtain GPS metadata associated with the photographs. This metadata can be used for direct georeferencing of the sUAS products and provide non-survey grade topography results suitable for manual interpretation (Carbonneau & Dietrich 2017).

A small number of survey participants expressed doubt that sUAS will be adopted by the restoration community due to challenges associated with navigating FAA regulations. We would like to address these concerns by highlighting recent efforts to incorporate sUAS into the national air space (FAA 2018) and new tools that streamline airspace authorization requirements, such as automated airspace authorization. Considering the positive responses from the survey, tackling the challenges of adopting sUAS for restoration applications would be well worth the effort. The USACE has already begun to explore the use of sUAS in their environmental programs (Suir et al. 2018), demonstrating logistical feasibility and demand for sUAS methods.

We have demonstrated a remote visual approach for stream ecological assessment using sUAS that fulfills a niche in the restoration practitioners' toolbox and can be built upon as new technology becomes more accessible. Although not a replacement for quantitative surface assessments when required, this approach is suitable when more general monitoring is satisfactory. As sUAS become more commonplace in society and in the assessment of aquatic ecosystems, restoration practitioners can look forward to a new suite of tools, both quantitative and qualitative, that will increase knowledge of restoration efforts from a landscape perspective.

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Illustrations:

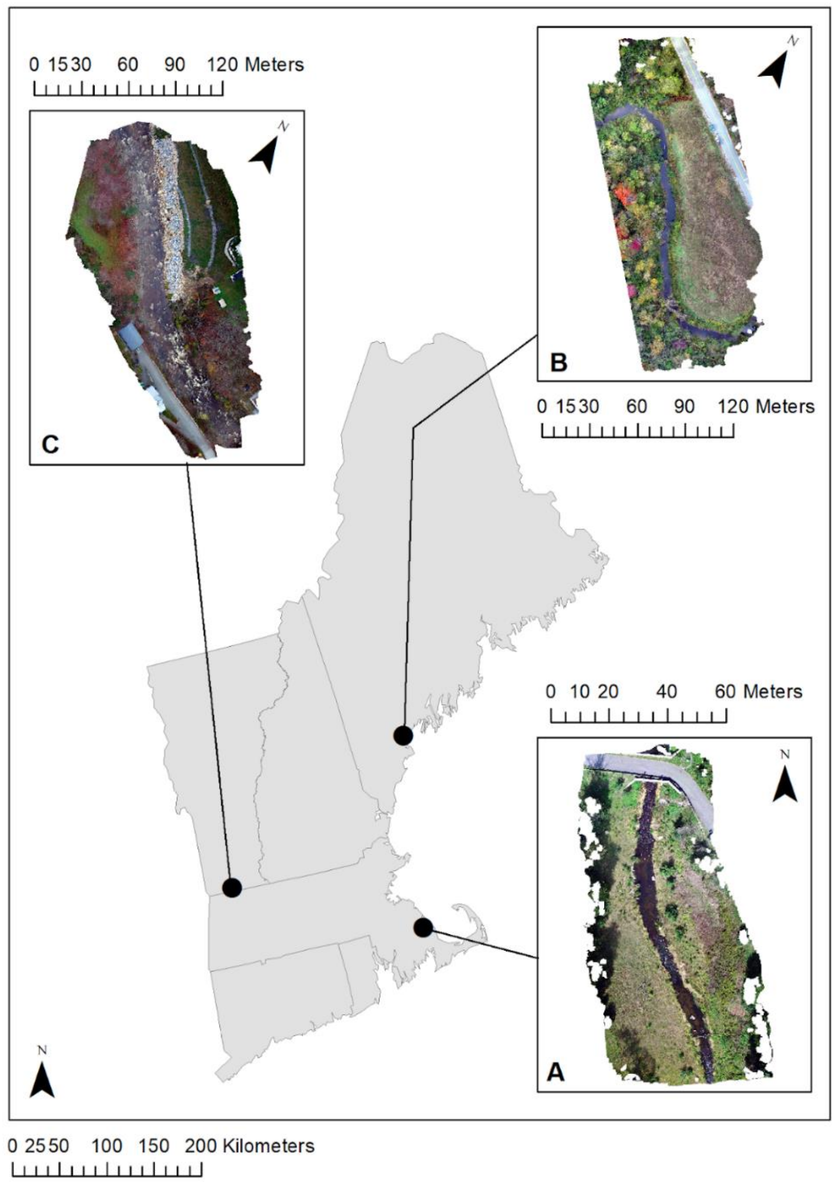


Figure 1: The three sites selected from the stream reaches visited by the USACE during their SVAP2 tour. (A) Town Brook in Plymouth, MA. (B) East Branch Piscataqua River in Falmouth, ME. (C) West Branch Deerfield River in Readsboro, VT. The MA site lies in the Atlantic Coastal Pine Barrens EPA ecoregion. This reach is the site of the Off-Billington Street Dam removal project. It has clear, shallow water, an early successional floodplain, and contains engineered habitat features. The ME site lies in the Northeastern Highlands EPA ecoregion. This

reach is a muddy, entrenched former agricultural site with slow moving, turbid water. One bank consists of forest while the other is adjacent to a field with a shrub line that contained many invasive plant species. The VT site also lies in the Northeastern Highlands EPA ecoregion. Unlike the site in Maine, this reach features a large bank stabilization project and the reach itself is set in a ravine. The topography combined with the clearer, rushing water and coarser cobble/boulder-dominated substrate differentiates this site. The orthomosaics shown were produced from the sUAS imagery. New England shapefile created by MassGIS.

Pre-Fieldwork	1. Investigate site (check FAA airspace, potential obstacles, flight permissions, etc.)	2. Plan automated flight paths	3. Import flight paths into mobile flight application
In the Field	4. Place GCPs throughout stream area (optional)	5. Survey GCPS (optional)	6. Execute flight paths to collect sUAS imagery
Post-Processing	7. Extract timed interval stills (if video collected rather than photos)	8. Process images (and GCP survey data, if collected) in SfM software to create sUAS products	9. Prepare sUAS products for sharing (e.g. annotate orthomosaic, create video)
Dissemination	10. Publish sUAS products on online platforms and further annotate (if needed)	11. Combine finished sUAS products links in one deliverable to share with stream experts	12. Share with stream experts to conduct remote visual ecological assessment

Figure 2: General sUAS product creation workflow. Details of the Agisoft PhotoScan Professional processing stream and site-specific workflow details can be found in the supporting information (Document S1, Table S1).

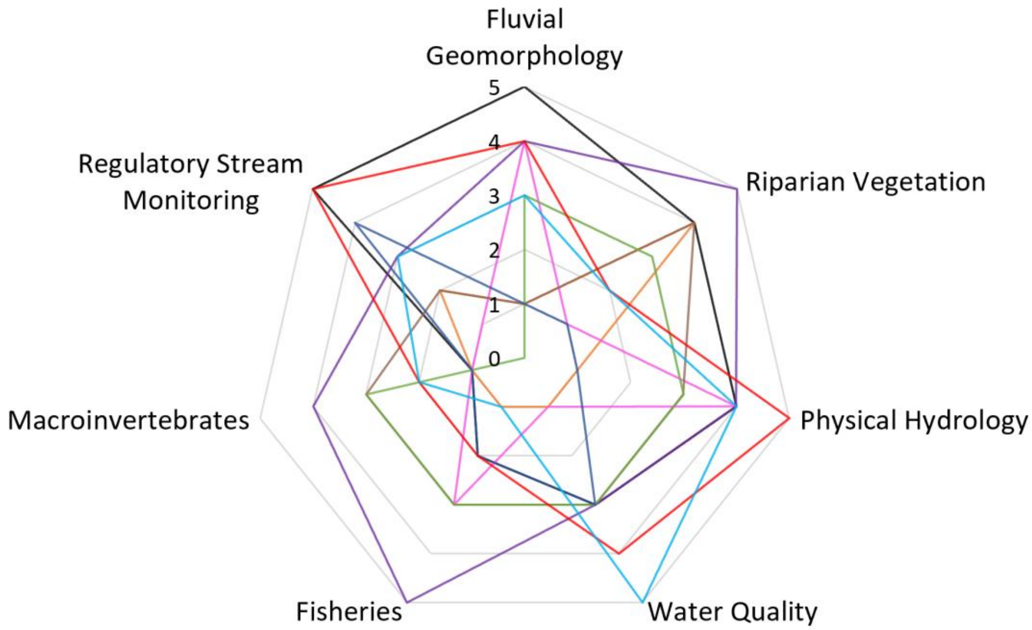


Figure 3: Visualization of the self-assessed areas of expertise from the nine survey participants who reported scores, with each color representing one participant. A score of zero indicates no expertise, while a score of 5 indicates a high level of expertise.

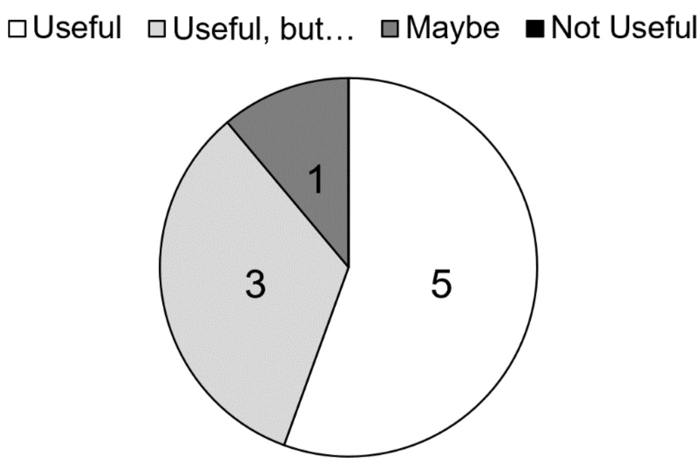
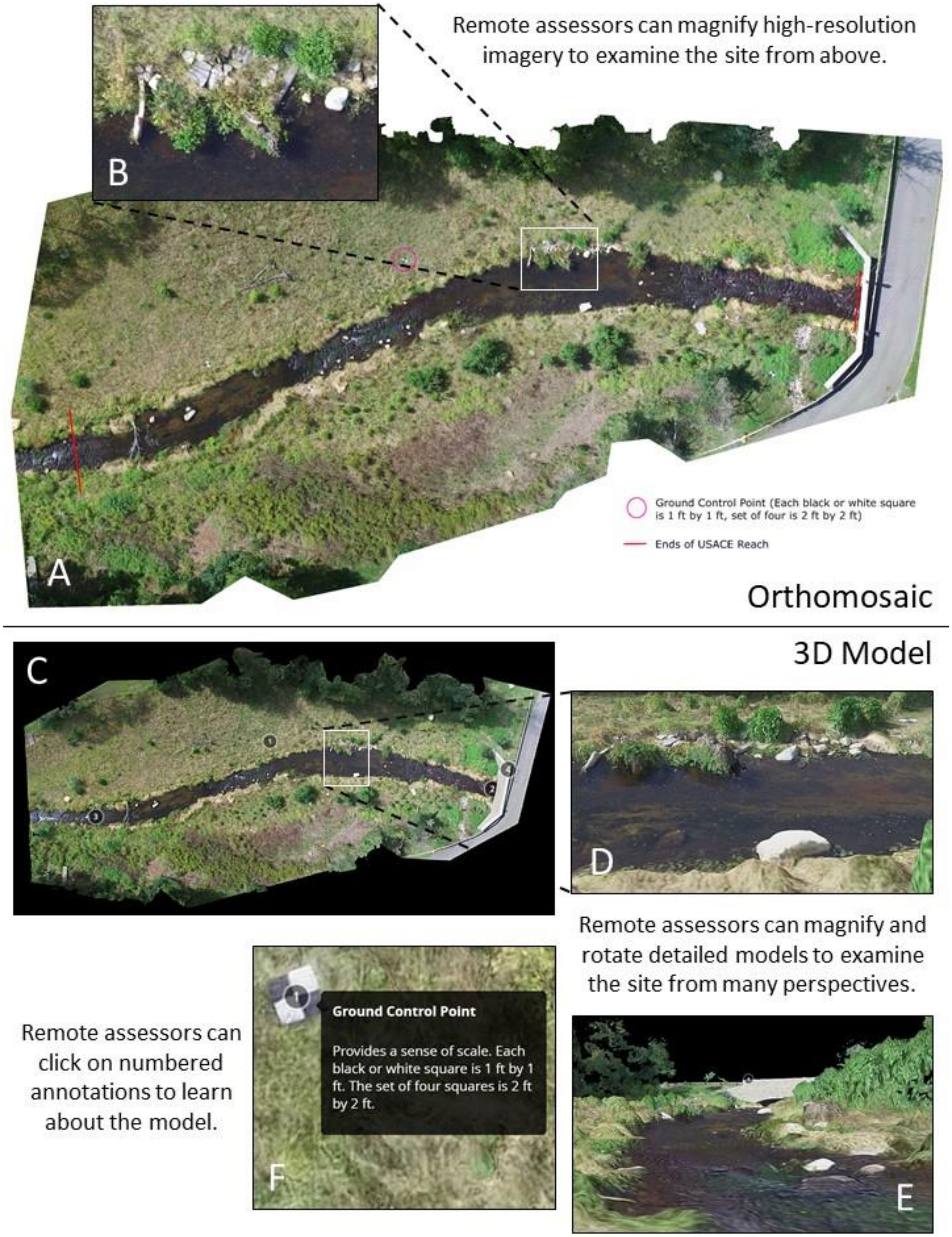


Figure 4: Categorized results for the survey question "Do you think having imagery and models such as these is useful for regulatory stream monitoring purposes? How about in the context of general restoration efforts?"



Remote assessors can magnify high-resolution imagery to examine the site from above.
B
Ground Control Point (Each black or white square is 1 ft by 1 ft, set of four is 2 ft by 2 ft)
Ends of USACE Reach
A
Orthomosaic
3D Model
C
D
Remote assessors can magnify and rotate detailed models to examine the site from many perspectives.
Remote assessors can click on numbered annotations to learn about the model.
Ground Control Point
Provides a sense of scale. Each black or white square is 1 ft by 1 ft. The set of four squares is 2 ft by 2 ft.
F
E

Figure 5: Illustration of the differences between the sUAS orthomosaics and 3D models using the MA site as an example. Image A is the annotated orthomosaic provided to the remote assessors. Image B shows a magnified version of some habitat features on the bank using the same orthomosaic. Image C shows the same aerial perspective the orthomosaic provides but using the 3D model. Image D shows a magnified oblique perspective of the 3D model highlighting the same habitat features in image B. Image E shows a perspective on the 3D model as if you were standing in the stream. Image F illustrates the numbered annotations on the 3D model that viewers can click on and scroll through to learn more about the model and site characteristics. Screenshots of the 3D model were taken from the viewer on the sketchfab website.

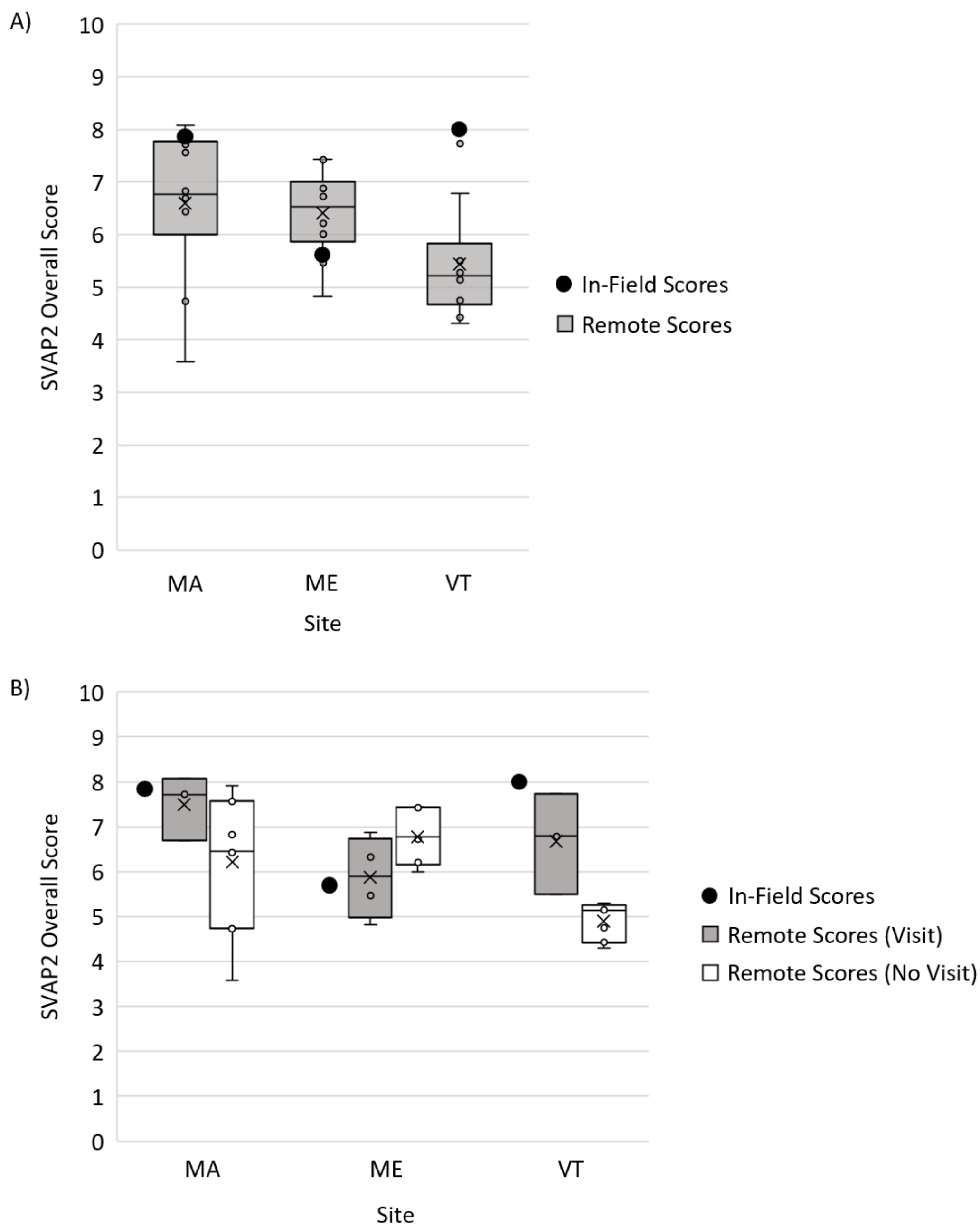


Figure 6: A comparison the remote overall SVAP2 scores provided by each survey participant to the score determined by the USACE team out in the field. “X” markers in box plots represent the mean remote score for each site. A) illustrates a general comparison, B) divides the remote participants by those who had visited the sites in person prior to the survey and those who had

not. Three out of the 10 participants had visited the MA site, four out of the 10 had visited the ME site, and three out of the 10 had visited the VT site.

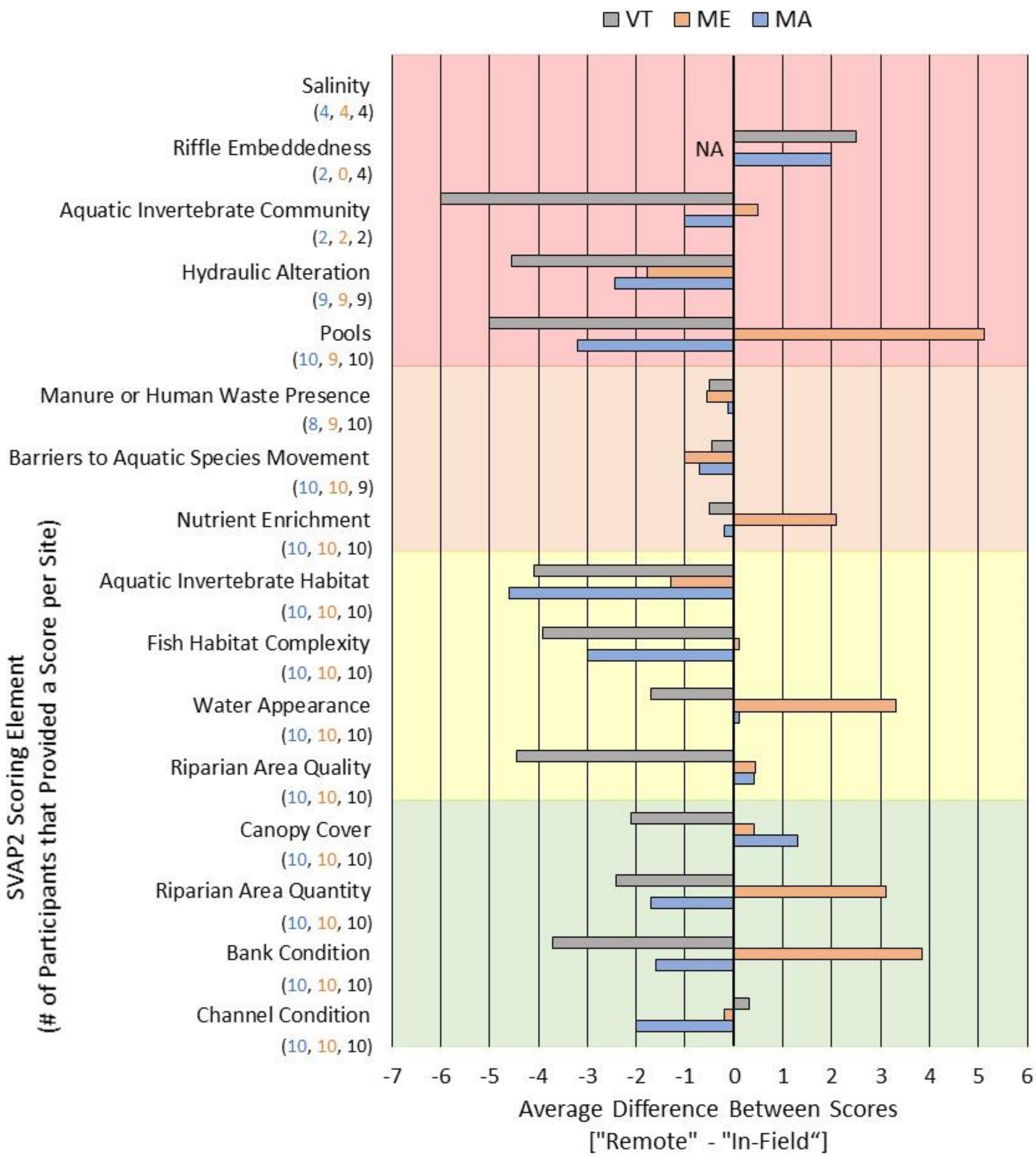


Figure 7: A comparison of the remote SVAP2 scores for each element across the sites against the in-field element scores. The average difference between the remote and in-field scores are shown

(calculated as “remote element score” - “in-field element score” for each participant’s responses). Negative values indicate that the remote approach underestimated the ecological condition relative to the in-field approach while a positive value indicates that the remote approach overestimated ecological condition relative to the in-field approach. The elements are organized by their feasibility to be evaluated using the remote sUAS assessment approach: (red) infeasible and not recommended for remote assessment, (orange) some aspects of SVAP2 scoring criteria possible, (yellow) feasible but with some limitations due to quality of sUAS products, (green) feasible and straightforward for remote visual assessment. Riffle embeddedness was deemed not applicable (NA) by the USACE team in the field at the ME site.

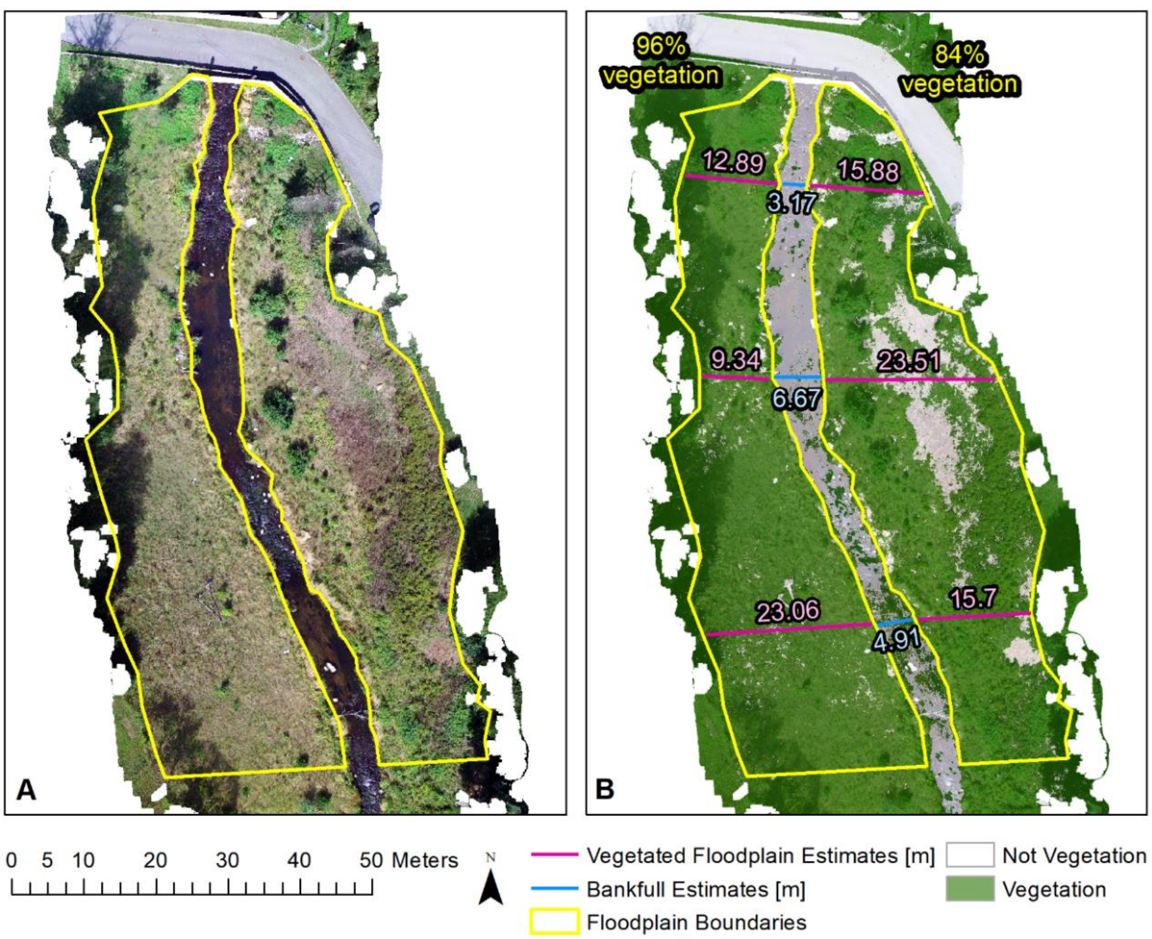


Figure 8: An example of how remote sensing and GIS can be used to calculate "true" ecological evaluation metrics analogous to the SVAP2 metrics. Specifically, this example depicts how this approach can calculate metrics related to the riparian area quantity element in the SVAP2. (A) MA site orthomosaic with assessment area. (B) MA site orthomosaic with partially transparent binary raster overlay showing the vegetation coverage throughout the site. A binary raster of vegetation cover was created in ArcGIS by using the raster calculator to first calculate the Green Leaf Index (GLI; Louhaichi et al. 2001), then again to select pixels with GLI values greater than 0.02 that represent vegetation. The zonal statistics tool in QGIS was used to calculate vegetation percent cover for each assessment area, with 96% vegetation cover calculated for the left bank and 84% vegetation cover calculated for the right bank. A bankfull width of 4.92 m was estimated by creating a set of three in-stream lines (towards the beginning, middle, and end of the reach), and averaging their length. Additional sets of three lines each were created perpendicular of the reach to estimate how far the vegetation continued into the floodplain. The lengths of these perpendicular lines were averaged for each bank (15.10 m left and 18.36 m right) and then divided by the bankfull width to estimate the extent of vegetation in the floodplain in terms of bankfull width. On average, the left bank had vegetation that extended 3.07 bankfull widths into the floodplain and the right bank had 3.73 bankfull widths.

SVAP2 Remote Scoring Element

Site or sUAS Product Characteristic	Channel Condition	Bank Condition	Riparian Area Quantity	Canopy Cover	Riparian Area Quality	Water Appearance	Fish Habitat Complexity	Aquatic Invertebrate Habitat
Glare on water or turbid water	O	O	O	O	O	X	X	X
Dense canopy cover over reach	X	X	X	O	X	X	X	X
Leaf-off Conditions	O	O	X	X	X	O	O	O
Relatively Low Product Resolution	O	O	O	O	X	O	O	X

Table 1: Summary of which SVAP2 remote scoring elements' feasibility would be impacted by certain site-specific or sUAS product quality complications. We selected elements deemed suitable for the remote visual approach for inclusion in the guide (green and yellow categories, Fig. 7). An "X" and a darker box indicates that if the complication is present, the element's feasibility for remote visual assessment could be compromised. An "O" indicates the element's feasibility would most likely not be compromised. These statuses were determined from the reasonings for each element score provided by the survey participants as well as the narrative responses. Relatively low resolution can occur when sUAS imagery is collected at a higher altitude.