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Testing the Use of Unmanned Aircraft Systems for Intertidal Surveys

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ABSTRACT

Intertidal monitoring is critical for supporting sustained ecosystem health and functioning as coastal systems are particularly vulnerable to environmental stressors and human impacts. Intertidal monitoring projects are often limited in their practicality because the spatial extent for which data can be collected by traditional methods, such as visual surveys or removal of biota, is constrained to sampling at low tide exposure periods. Here, we used imagery from a small unmanned aerial system (sUAS) to test their potential use in rocky intertidal and intertidal seagrass surveys in the northern Gulf of Alaska. Images captured by the sUAS in the high, mid, and low intertidal strata on a rocky beach and within a seagrass bed were compared to data derived from concurrent observer visual surveys and images taken by observers on the ground. Observer visual data always resulted in the highest taxon richness; however, when observer data were aggregated to the same taxonomic resolution obtained by the sUAS images, overall community composition was mostly similar between the two methods. Ground camera images and sUAS images yielded mostly comparable community composition despite the typically higher taxonomic resolution obtained by the ground camera. We conclude that monitoring goals or research questions that can be answered on a relatively coarse taxonomic level can benefit from an sUAS-based approach because it allows much larger spatial coverage than is possible by observers on the ground. We demonstrated this large-scale applicability by using sUAS images to develop maps that show the distribution patterns and patchiness of seagrass.

INTRODUCTION

Monitoring and assessing biological communities in intertidal habitats is a common practice and much needed in our changing climate because these communities will be among the first to exhibit impacts (Helmuth et al., 2006). Traditional intertidal monitoring is restricted to low tide events when researchers can manually quantify organisms using percent cover, abundance, biomass, or similar measurements (Konar et al., 2009; Leujak and Ormond, 2007; Menge et al., 2015). In the field, this is typically done by a small team of surveyors who assess species composition from quadrats or transect lines along intertidal strata. Quadrat sampling is a tested, accurate, and efficient sampling method for quantifying benthic biological communities (Heltshe and Forrester, 1985; Obermeyer, 1998) and is a mainstay in monitoring programs (Delaney et al., 2008; Konar et al., 2009) and impact studies (Cox and Foster, 2013; Minchinton and Fels, 2013). For example, in the Gulf of Alaska, quadrat sampling was broadly used in assessing damage and intertidal recovery after the *Exxon Valdez* oil spill (Boehm et al., 1996; Skalski et al., 2001; Stekoll and Deysher, 2000) and is still being used by the current Gulf Watch Alaska intertidal monitoring program (Konar et al., in press). The advantages of this type of traditional survey method are that experts can identify the species in the field at a high taxonomic resolution and can collect vouchers of unknown organisms for later identification. Despite its wide application, quadrat sampling in intertidal systems has the inherent problem of being spatially limited because only small stretches of beach (on the order of 10s to 100s of meters) can typically be surveyed per low tide interval. This spatial limitation can cause problems in representatively capturing species occurrence and distribution, intertidal community structure, and variability in community composition.

In addition to traditional sampling, photographic surveys have proven to be an effective and cost efficient method for accessing benthic communities (Aronson et al., 1994; Bohnsack, 1979; Witman et al., 2004). Photographic methods provide advantages over traditional in situ surveys because photographs reduce the time required in the field to collect quadrat information, and images offer a permanent historical record (Reimers et al., 2014, although see Foster et al., 1991). While use of imagery can reduce the time it takes to sample a single quadrat (Bohnsack, 1979), the amount of beach that can feasibly be sampled remains limited to the short low tide period because surveyors need to walk along the beach stratum and photograph each sample.

Recently, other means of acquiring photographs across broader areas have been tested. For example, kite aerial photography produced maps that covered 200 m of intertidal shoreline (Bryson et al., 2013). These photographs were used to construct high-resolution, three-dimensional, multi-spectral terrain models of rocky intertidal shores. Similarly, low-altitude aerial photography from a balloon-mounted digital camera platform was used to acquire an intertidal landscape mosaic of eelgrass (*Zostera marina*) and blue mussels (*Mytilus edulis*) (Barrell and Grant, 2015). Also, multispectral LiDAR surveys have been used to evaluate the structural complexity of coastal habitats (kelp habitat, eelgrass meadow, beach, salt-marsh, farm, and urban coastal environments) and to classify the spatio-temporal distribution of these habitats across a large spatial area (Collin et al., 2012). Photographic and video surveys from airplanes have become common for characterizing intertidal communities, as demonstrated by the National Oceanic and Atmospheric Administration (NOAA) ShoreZone mapping program along most of Alaska's shoreline and much of the US west coast (www.shorezone.org). While the use of various types of aerial photography has allowed for the expansion of the spatial extent of intertidal surveys, the resulting imagery has not been used to identify intertidal organisms at the taxonomic resolution needed for biological monitoring.

Ideally, an intertidal method should allow sampling to be completed quickly, cover much spatial area, and have high enough taxonomic resolution to inform accurate and detailed biological descriptions of large intertidal areas. We suggest that a small Unmanned Aerial System (sUAS) equipped with a high-resolution camera can be used to spatially expand biological intertidal sampling. We tested this methodology for an ongoing rocky intertidal and intertidal seagrass monitoring program in the Gulf of Alaska. In Alaska, sUASs have been successfully operated in marine mammal monitoring, resource mapping, and mapping sea ice and glaciers (Koski et al., 2009; Walker, 2012). However, altitudes flown for those purposes are too high to produce images at the taxonomic resolution required for most biological intertidal monitoring programs. Here, we flew a small, camera-mounted sUAS at low altitude to test if resulting images would allow for the analysis of percent cover of individual intertidal taxa or taxon groups. We also tested the use of sUAS images of an intertidal seagrass bed to assess percent cover of seagrasses versus other taxa. In addition, we used imagery over the seagrass bed to produce large-scale (on the order of 100s of meters) coverage of the bed to assess variability in seagrass cover, which is difficult to achieve for a representative area doing ground surveys. Seagrass bed size and patchiness are important monitoring metrics because seagrass beds tend to shrink in size under high sedimentation conditions such as from coastal erosion (Cabaço et al., 2008). Therefore, our primary objective was to determine if sUASs can be used to spatially expand current traditional rocky intertidal and intertidal seagrass monitoring. We tested the hypotheses that observer data would yield higher taxonomic resolution than images taken by a camera mounted to an sUAS and that there would be no difference between methods when applied at a unified, coarse taxonomic level. We also hypothesized that community composition determined from images taken on the ground by observers would not be different to that determined from images taken by the sUAS. Lastly, we hypothesized that sUAS images could be used to create large-scale distribution maps of seagrass cover.

METHODS

This study took place in April to May 2015 in Kachemak Bay, Alaska, in the northern Gulf of Alaska at 59.7257˚ N and 151.1410˚ W, where ongoing intertidal monitoring efforts through the Gulf Watch Alaska program (www.gulfwatchalaska.org) include the biological assessment of rocky intertidal and intertidal seagrass systems. We paired the annual monitoring of two permanent intertidal sites with an sUAS team, which included an sUAS pilot, to conduct this study. For this, a camera-equipped sUAS was deployed at one rocky, macroalgal-dominated beach and one soft-bottom seagrass intertidal site in Kachemak Bay, Alaska (Figure 1). The sUAS was a quadcopter Aeryon Scout™, which carried a GoPro Hero 3, 12-megapixel camera modified with a rectilinear lens to eliminate the fish-eye effect. At the rocky intertidal site, the sUAS was deployed at the mean higher high water (MHHW), the mean tidal level (MTL), and the mean lower low water (MLLW) level (see Konar et al., 2009). At the seagrass site, the sUAS was deployed from a single starting point on the beach and flown in various directions across the seagrass bed. In both intertidal systems, the sUAS was flown at an altitude of approximately 5 m at very low speeds of approximately 2 km/h to maximize the resolution of the imagery. Images were taken every 1-5 seconds, depending if images were taken solely or grabbed from video.

Figure 1: Map showing the seagrass and rocky sites within Kachemak Bay. The red box on the inset map shows the location of the study area within Alaska.

A field team conducted biological ground surveys at the same times and locations as the sUAS deployments. A 50-m transect tape was placed at each depth stratum (MHHW, MTL, and MLLW) at the rocky site and one 50-m transect was placed in the center of the seagrass site to orient the sUAS and ensure that the sUAS surveyed the same spatial area as the ground crew. A quadrat (1-m^2 at rocky site, 0.25-m^2 at seagrass site) was placed along each transect to allow us to compare the size of an sUAS image to a ground image or survey plot. At the rocky intertidal site, the observer surveys included the visual estimation of percent cover of macroalgae, sessile invertebrates (such as mussels and barnacles), and bare substrate in ten randomly-placed 1-m^2 quadrats along transects at each of the tidal strata (Figure 2). A photograph was taken of each quadrat and used for comparisons with the sUAS images. Each rocky intertidal stratum was examined separately because strata differ significantly in community composition and are not comparable in this region (Konar et al., 2009). At the seagrass site, percent cover of seagrass and other groups such as mussels, macroalgae, diatom mats, and open substrate was calculated from five randomly-placed 0.25-m^2 quadrats placed along a 50-m transect in the approximate center of the bed (Figure 3). A picture was taken of each quadrat to compare with five randomly selected sUAS image frames along this transect. To assess the distribution and patchiness in seagrass cover over a larger spatial extent, we flew the sUAS along extended haphazard flight paths over the seagrass bed.

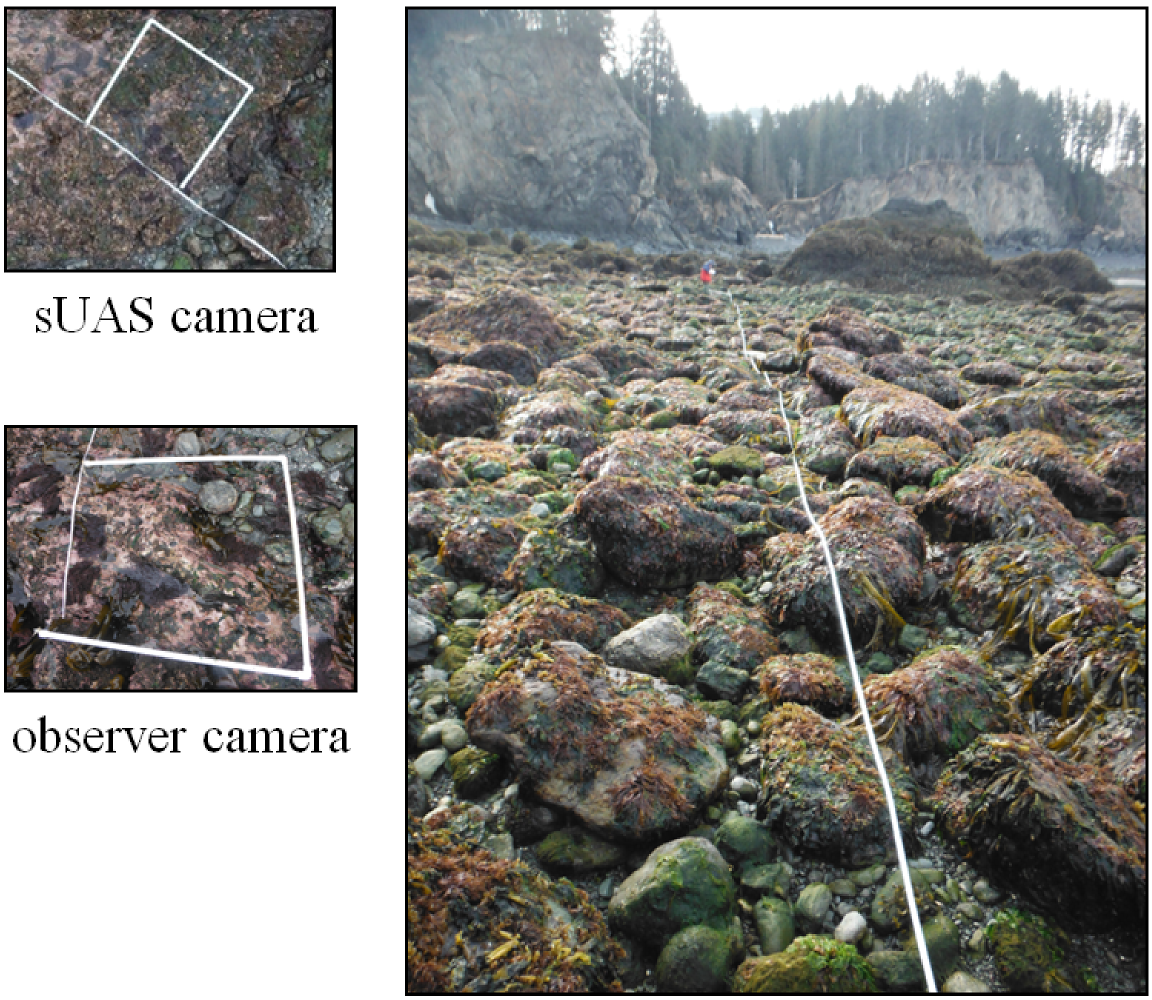

Figure 2: Transect layout and example images taken from the sUAS and ground observer cameras from the rocky intertidal MTL.

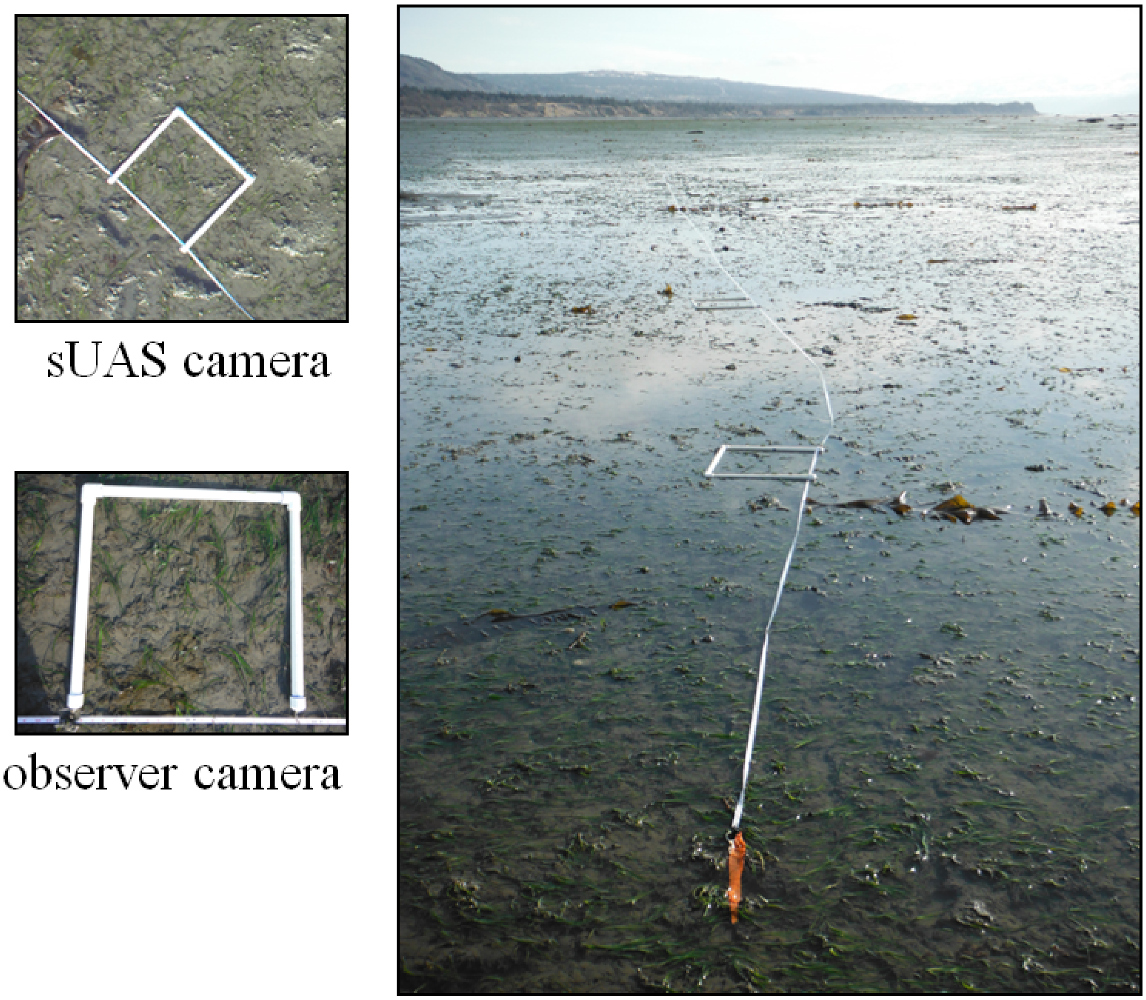

Figure 3: Transect layout and example images taken from the sUAS and ground observer cameras from the seagrass system.

Percent cover was determined from images taken on the ground as well as ten randomly selected images taken by the sUAS along each 50-m transect in each system (Figure 2). Data were collected at the finest taxonomic resolution (fine) produced by each of the three methods (sUAS image, ground image, and observer visual). We then aggregated the observer ground data at the taxonomic resolution achieved from sUAS images to test our hypothesis that community composition at that coarse taxonomic level is comparable between the two methods. For the comparison of sUAS images and ground camera images, we only used the fine taxonomic resolution.

For both intertidal systems, we compared the mean percent cover for the individual coarse taxon groups between observer data and sUAS images using t-tests at a significance level of $\alpha=0.05$ (SYSTAT v10). The overall community compositions for rocky intertidal and seagrass systems were compared at fine and coarse taxonomic resolutions for sUAS images versus observer data and at fine taxonomic resolution for sUAS images versus ground camera images. In the rocky intertidal, this was done separately for each tidal stratum. We used nonmetric Multidimensional Scaling (nMDS) to visualize the data and Analysis of Similarity (ANOSIM) to determine differences between the sampling methods (Primer-e V7). An ANOSIM yields global R values that range from 0 to 1, with smaller values indicating little differences in community structure and R values above 0.45 considered to represent biologically relevant differences in community composition (Clarke et al., 2014). In cases where we detected differences between sUAS images and observer data at the coarse taxonomic level, we used a Similarity Percentage Analysis (SIMPER) to determine the taxon categories that contributed most to the differences in community composition. Similarly, we used SIMPER to determine the categories that contributed most to community differences detected in comparisons between the sUAS and ground images at the fine taxonomic resolution.

For the large-scale analysis of patchiness in the seagrass bed, we selected non-overlapping images from a total of four flights with relatively even flight height (~ 5 m) as assessed from the altimeter information recorded by the sUAS camera. For each image (n=662 for all flights combined), we estimated the percent cover of seagrass in the image area. We then took the GPS coordinates of each image and converted them into eastings and northings to convert coordinates into actual distances (in meters) and to avoid spatial distortion. We spatially plotted the seagrass percent cover using a linear interpolation function to create a "heat map" to visualize regions of high and low seagrass cover or spatially plotted individual data points using Matlab.

RESULTS

In the rocky intertidal, observer percent cover surveys at the fine taxonomic resolution yielded 10, 25, and 24 different taxa/categories at the MHHW, MTL, and MLLW, respectively (Table 1). This was much higher than obtained from the sUAS images at the fine resolution, with 4, 9, and 10 taxa/categories at the same tidal strata. The observer camera images yielded similar or slightly higher taxon/category numbers as the sUAS images, with 5, 10, and 10 categories at the MHHW, MTL, and MLLW, respectively. The higher taxonomic resolution from the observer data primarily came from macroalgae that could be identified to species level by observers but required grouping into larger categories for camera and sUAS images (Table 1). Data from the ground observers and sUAS images were then unified at the coarser taxonomic level available for the sUAS images and grouped into 4 categories at the MHHW, 10 categories at the MTL, and 10 at the MLLW (Figure 4). At the MHHW, significant differences between observer and sUAS data existed for the macroalgae and rock/shell categories (Table 1, Figure 4). At the MTL, the only significant differences in categories between the two methods were for kelp and other green algae; however, kelp occurred at a very low percentage in that tidal stratum. At the MLLW, significant differences between the two methods were observed for *Palmaria* spp., *Polysiphonia/Pterosiphonia*, and *Cladophora/Acrosiphonia* categories. Of these, the *Cladophora/Acrosiphonia* category was the only one of the significant groups that had higher percentages in the sUAS images than in the observer data (Figure 4).

Table 1. ANOSIM results of comparisons between observer and sUAS data, and between sUAS and camera data. Taxonomic resolution used for each comparison is listed as Tax. Res. The taxonomic categories for each data set are listed.

Stratum	Comparison	Tax. Res.	ANOSIM	Taxonomic categories
MHHW	sUAS-observer	fine	0.768	**sUAS (4):** other macroalgae, Fucus, rock/shell, barnacles **observer (10):** Fucus, Gloiopeltis furcata, Odonthalia floccosa, Mazzaella sp. Pterosiphonia bidentata, Cryptosiphonia woodsii, Endocladia muricata, rock/shell, barnacles, mussels
MHHW	sUAS-observer	coarse	0.438	**both (4):** other macroalgae, Fucus, rock/shell, barnacles
MHHW	sUAS-camera	fine	0.833	**sUAS (4):** other macroalgae, Fucus, rock/shell, barnacles **observer (5):** other macroalgae, Fucus, rock/shell, barnacles, mussels
MTL	z	fine	0.736	**sUAS (9):** Fucus, Palmaria spp., Cladophora/Acrosiphonia, Ulva/Monostroma, encrusting corallines, other red algae, other green algae, barnacles, rock/shell **Observer (25):** Fucus, Saccharina sessilis, Alaria sp., Scytosiphon lomentaria, Acrosiphonia sp., Cladophora sp., Monostroma grevillei, Ulva intestinalis, Ulva lactuca, Ulva linza, Neorhodomela sp., Halsosaccion glandiforme, Mazzaella sp., Palmaria callophylloides, Palmaria hecatensis, Pterosiphonia/Polysiphonia, Cryptosiphonia woodsii, Odonthallia floccosa, Microcladia borealis, Tokidadendron sp., Porphyra/Pyropia-complex, Corallina vancouveriensis, encrusting corallines, barnacles, rock/shell
MTL	sUAS-observer	coarse	0.200	**both (10):** Fucus, kelp, Cladophora/Acrosiphonia, Ulva/Monostroma, Palmaria spp., encrusting corallines, other red algae, other green algae, barnacles, rock/shell
MTL	sUAS-camera	fine	0.208	**sUAS (9):** Fucus, Cladophora/Acrosiphonia, Ulva/Monostroma, Palmaria spp., encrusting corallines, other red algae, other green algae, barnacles, rock/shell. **camera (10):** Fucus, Saccharina sessilis, Cladophora/Acrosiphonia, Ulva/Monostroma, encrusting corallines, Pterosiphonia/Polysiphonia, Halosaccion glandiforme, Palmaria spp., barnacles, rock/shell
MLLW	sUAS-observer	fine	0.736	**sUAS (10):** Cladophora/Acrosiphonia, Ulva/Monostroma, Palmaria spp., encrusting corallines, kelp, Pterosiphonia/Polysiphonia, other red algae, other green algae, barnacles, rock/shell **Observer (24):** Fucus, Saccharina sessilis, Alaria sp., Scytosiphon lomentaria, Acrosiphonia sp., Monostroma grevillei, Ulva intestinalis, Ulva lactuca, Halsosaccion glandiforme, Mazzaella sp., Palmaria callophylloides, Palmaria hecatensis, Ahnfeltia sp., Pterosiphonia/Polysiphonia, Cryptosiphonia woodsii, Odonthallia floccosa, Microcladia borealis, Tokidadendron sp., Porphyra/Pyropia-complex, Corallina vancouveriensis, encrusting corallines, diatoms, barnacles, rock/shell
MLLW	sUAS-observer	coarse	1.354	**both (10):** Fucus, kelp, Cladophora/Acrosiphonia, Ulva/Monostroma, Palmaria spp., Pterosiphonia/Polysiphonia, encrusting corallines, other macroalgae, barnacles, rock/shell
MLLW	sUAS-camera	fine	0.100	**sUAS (10)** Cladophora/Acrosiphonia, Ulva/Monostroma, Palmaria spp., Pterosiphonia/Polysiphonia, encrusting corallines, kelp, other red algae, other green algae, barnacles, rock/shell **camera (13):** Fucus, Saccharina sp., Alaria sp., Saccharina sessilis, Halosaccion glandiforme, Cladophora/Acrosiphonia, Ulva/Monostroma, Palmaria spp., Pterosiphonia/Polysiphonia, encrusting corallines, other green algae, barnacles, rock/shell

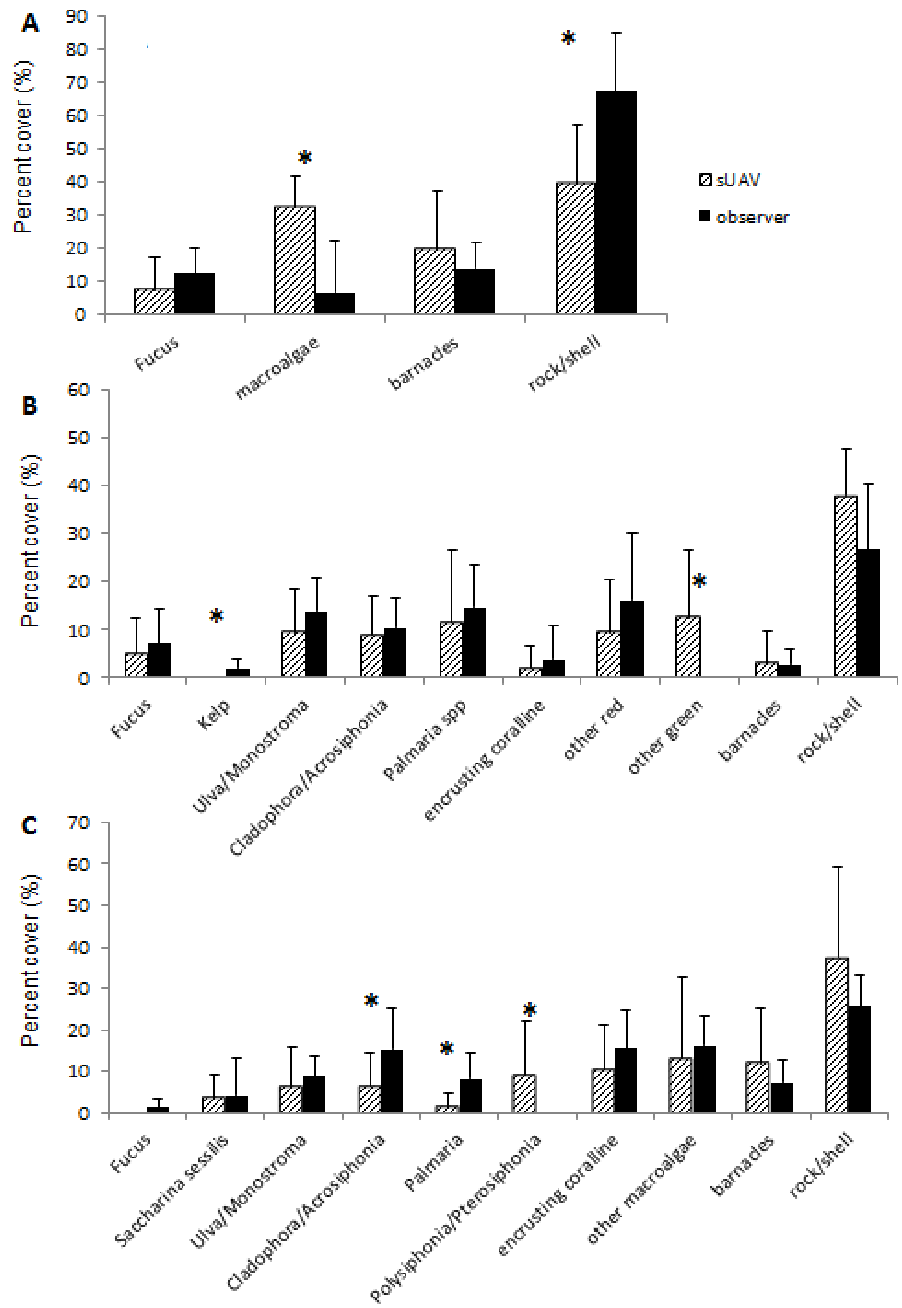

Figure 4: Comparison of percent cover (observer surveys versus sUAS images) of coarse taxonomic categories from the rocky intertidal site. A) MHHW, B) MTL, C) MLLW. Asterisks above bars indicate statistical differences for the respective category between sUAS images and observer surveys (at $p \leq 0.05$; results from t-test).

Similarities in the overall community composition between the observer and sUAS images depended mostly on the taxonomic resolution used but also varied slightly by the rocky intertidal stratum considered (Figure 5). As expected, observers always produced the highest taxon number in each tidal stratum, and community structure based on fine taxonomic resolution (i.e., the highest resolution yielded by either method) was always different between observer data and sUAS data (Figure 5 - fine, Table 1). When the taxonomic resolution of the observer data was brought to the same level as the sUAS images, community composition was no longer different between the two methods. However, at the MHHW, statistical results were near the threshold at which biologically meaningful differences could occur (ANOSIM R=0.436) (Figure 5 - coarse, Table 1). When combined, categories macroalgae and barnacles contributed the most (58%) to the differences in community structure at the MHHW (SIMPER analysis) and were both higher in the sUAS images than the observer data. When comparing the two image systems (sUAS and ground camera), we found a strong community difference at the MHHW but not at the other two strata (Figure 6, Table 1). As for the comparison between sUAS images and observer data, macroalgae and barnacles again contributed most to the community differences (56%, SIMPER), and both categories were higher in the sUAS images. Both image systems yielded very similar community compositions at fine resolution at both the MTL and MLLW (Figure 6, Table 1).

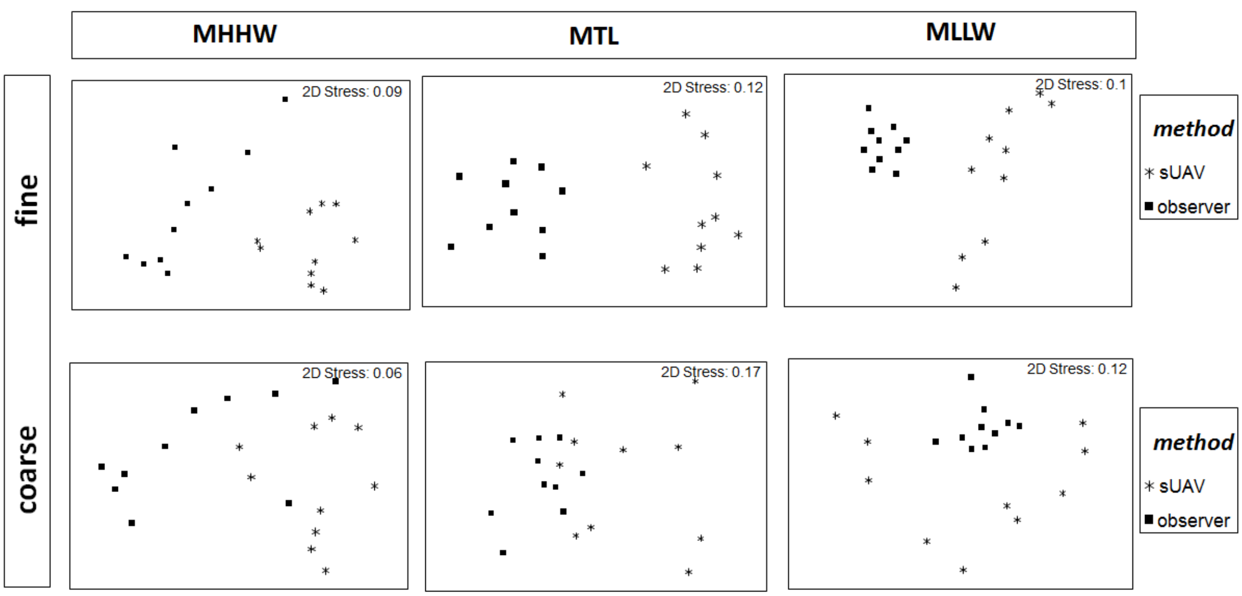

Figure 5: nMDS ordinations of images taken by the sUAS and observer visual surveys for the MHHW, MTL, and MLLW tide levels. nMDS are shown for the fine (upper panel) and coarse (lower panel) taxonomic resolutions at each rocky intertidal stratum. All data were square-root transformed, and nMDS are based on Bray-Curtis similarity matrices. For ANOSIM results see Table 1.

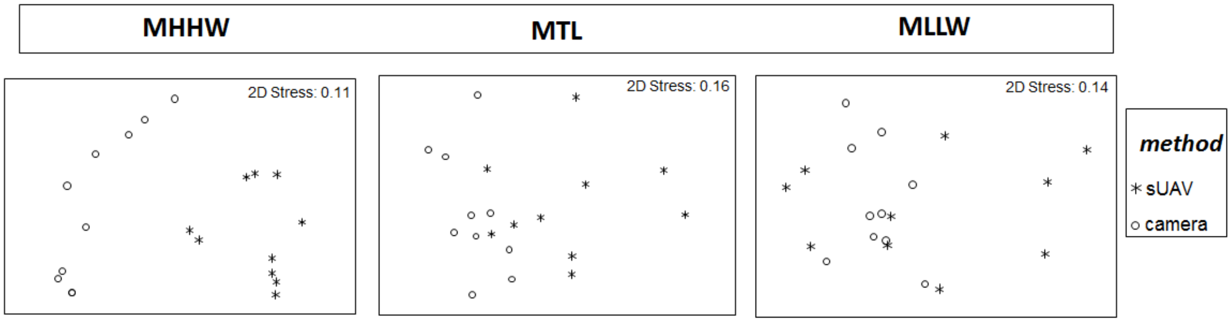

Figure 6: nMDS ordinations of community structure from images taken by the sUAS versus images from the ground camera for MHHW, MTL, and MLLW tide levels. nMDS are shown for the fine taxonomic resolution at each rocky intertidal stratum. All data were square-root transformed, and nMDS are based on Bray-Curtis similarity matrices. For ANOSIM results see Table 1.

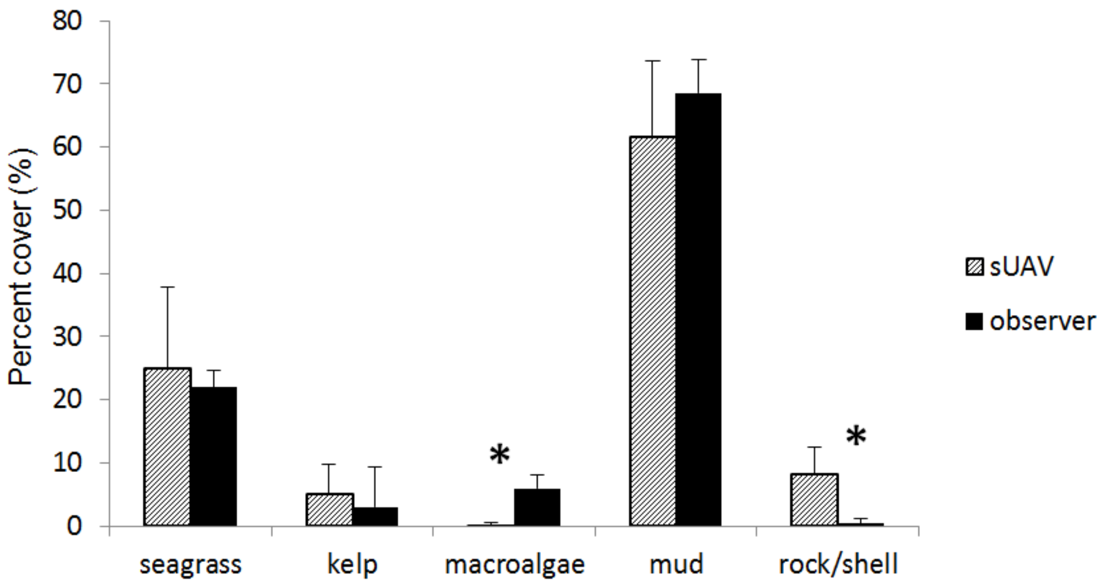

Figure 7: Percent cover of coarse categories from the seagrass bed as assessed by observer surveys and images taken by the sUAS. Asterisks above bars indicate statistical differences for the respective category between drone images and observer surveys (at $p \leq 0.05$; results from t-test).

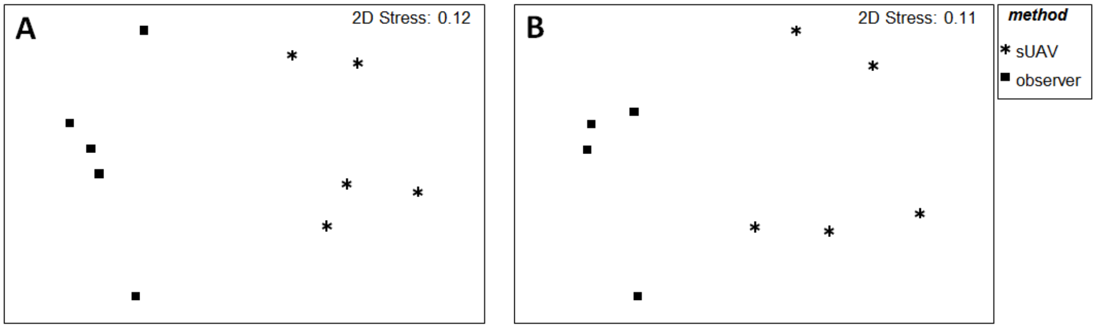

Figure 8: nMDS ordinations of A) fine, and B) coarse taxonomic resolution community composition from images taken by the sUAS versus observer visual surveys. All data were square-root transformed and nMDS are based on Bray Curtis similarity matrices. For ANOSIM results see text.

Based on the result that seagrass percent cover taken by observers and from sUAS images were not significantly different (see Figure 7), we used the sUAS images from a larger spatial extent to assess variability in seagrass cover. The heat map based on percent cover of seagrass from sUAS images clearly identified the high-density center of the seagrass cover, with sharply decreasing concentrations towards the edges of the bed (Figure 9, left panel). Plotting the percent cover for each image, instead of using interpolation, can be a useful tool to document occasional but, strong small-scale variation in seagrass cover (Figure 9, right panel). Small-scale variability was especially obvious in the center of the bed where neighboring images showed seagrass cover from 10 to 80% (see circle in Figure 9, right panel).

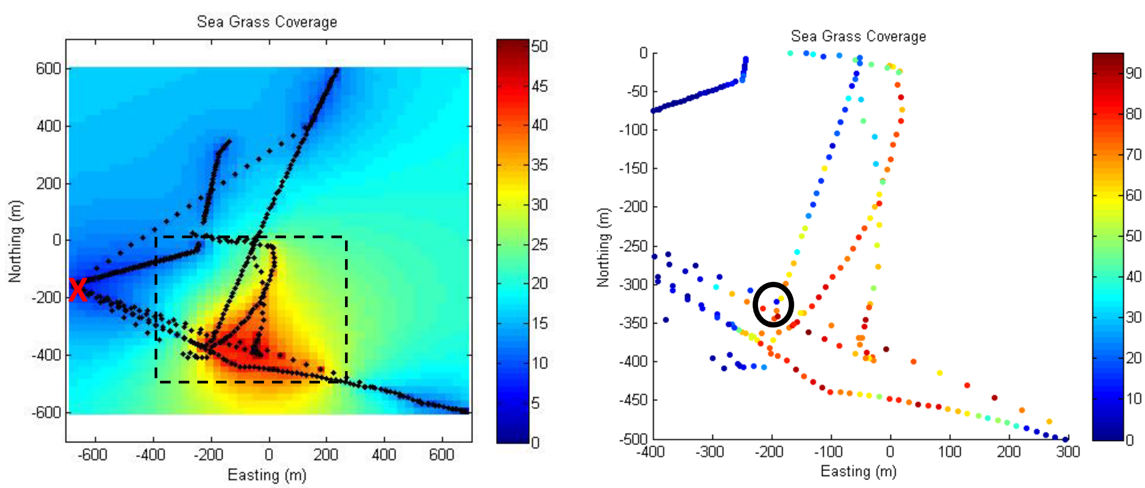

Figure 9: Percent cover of seagrass derived from sUAS images during flights across the seagrass bed. Left: Heat map of seagrass cover according to the scale on the right as % seagrass cover; black dots indicate pictures taken during the flight paths; dashed outline indicates the part of the plot displayed in detail in right panel. The “X” at the left side of the plot indicates the beach location where the sUAS started and returned. Right panel: Seagrass cover according to color scale given to the right for each individual image during flight paths, focusing on the center of the seagrass bed. The circle indicates a region of high patchiness in seagrass cover among neighboring images.

DISCUSSION

The data support our hypothesis that observer percent cover surveys on the ground consistently achieve a higher resolution of taxonomic categories compared with sUAS images. Most of these differences resulted from the much higher taxonomic resolution of macroalgae obtained by the observers in both the rocky intertidal and seagrass systems (see Table 1). Naturally, observers on the ground have more means to determine taxonomic features of macroalgal species identification such as texture, branching patterns, holdfast structure, and natural color. Also, an observer can move organisms to get a better view of other partially hidden organisms, which is not possible with an image. These advantages may be especially important for taxa that occur at a very low percent cover. A study comparing various methods of estimating benthic cover in rocky intertidal systems found that photographic images can reliably identify taxa that occur at >30% in a plot (Meese and Tomich, 1992). The likelihood that taxonomic features will be discernable on an image should increase when a larger area is covered by a taxon. Many of the algal species in our study, in both rocky intertidal and seagrass systems, covered much less than 30% of the area. In fact, many taxa covered just 1-5%, making it more likely that they were overlooked or not distinguishable on an image. Glare in many of the images and insufficient pixel resolution of the sUAS camera also made it difficult to distinguish small features. The number of macroalgal species in rocky intertidal systems has been proposed as a useful monitoring metric for water quality and system ecological health (Wells et al., 2007). That study, however, also recognized that reliability of species identification depends heavily on observer expertise and needs to be carefully evaluated. Thus, assessment of community structure on a coarser taxonomic level may be more reliable for monitoring purposes when taxonomic expertise cannot be guaranteed.

In most cases, percent cover of individual categories and overall community composition were very similar once the observer data were aggregated at the taxonomic resolution level of the sUAS images in the rocky intertidal, supporting our hypothesis in most cases. We still detected notable differences in community structure at the coarse taxonomic resolution at the MHHW. On an individual species level at the MHHW, sUAS images yielded higher macroalgal cover while observer data yielded higher rock/shell cover (Figure 4A); however, on a community-wide level, macroalgae and barnacles contributed most to the community differences. It is possible that the white barnacles are not easily distinguished from light-colored rock on an image in the high intertidal and that the small size of many high intertidal macroalgal species (e.g., *Gloiopeltis furcata* and *Endocladia muricata*) renders them cryptic in an image. In addition, or alternatively, it is possible that spatial variability in the MHHW is so high that the randomly chosen observer plots and randomly chosen sUAS images happened to capture different aspects of this community. The fairly high scattering of replicate samples for both sUAS and observer data in the nMDS plots suggests that spatial variability is high in the MHHW in this system (Figure 5). While most of the spatial variability in rocky intertidal systems is associated with the vertical extent of the system (i.e., the tidal strata), a significant amount can also be associated with the horizontal extent along a transect (Araújo et al., 2005; Konar et al., 2009).

Similarly to the MHHW, we found significant differences in some individual species percent covers at the MTL and MLLW (Figures 4B, 4C), although the community-wide structures were highly similar (Figure 5, Table 1). Community analysis is a multi-species, permutational approach using rank-based data to calculate similarities of samples and, thus, the species that contribute to the multivariate differences in community structure are not always the same as those where abundances differ in single species comparisons (Clarke, 1993; Clarke et al., 2014). Therefore, the coarse taxonomic level achievable with an sUAS can be a useful tool if the goal of the monitoring is to assess changes in overall community structure or monitoring non-biological beach attributes. For example, sUASs were successfully used for monitoring disturbance in a rocky intertidal in northern Spain by comparing images of boulder position over time (Pérez-Alberti and Trenhaile, 2015). If the goal of the monitoring is to assess overall species richness or the abundance of specific species, the sUAS resolution may not be sufficient. It has been suggested that presence of opportunistic species is an important metric in rocky intertidal monitoring (Juanes et al., 2008; Wells et al., 2007), and it would be important to select such opportunistic species for a specific region in which to conduct monitoring. Should such species be recognizable on sUAS images, sUAS surveys could become a highly valuable tool. In previous work in the northern Gulf of Alaska, we determined that the genus or order levels of macroalgal identification, or groupings on a functional level, are sufficient to distinguish community patterns among various regions (Konar and Iken, 2009). While the sUAS did not consistently provide sufficient resolution on the genus or order level for all species, our results here are promising to test if the sUAS imaging approach could be useful to detect larger spatial scale (regional) differences in community structure on the coarse resolution.

We hypothesized that ground camera and sUAS images would provide comparable community-level data. This was true for the rocky intertidal habitat at the MTL and MLLW but not at the MHHW. Observer surveys had an advantage over both imaging techniques in that observers could more reliably capture detailed taxonomic features and could move organisms aside to clear a partially hidden organisms underneath. However, the quality and resolution of ground images, typically taken from < 2 m height, was much higher than quality and resolution of sUAS images taken from a greater height. The better resolution of the camera images may have contributed to the greater detection of barnacles and small red algae, the two categories that contributed most to the differences in community structure. However, a slightly higher taxonomic resolution achieved with the ground camera versus the sUAS (see Table 1) did not affect results on the community level at the two lower tidal strata. Therefore, sUAS imagery could be an alternative to the more time-consuming method of walking along the tidal strata at low tide to capture ground images. Cost-benefit analyses would need to be done for specific projects to see whether sUAS imagery is also more cost effective.

In the seagrass system, the main difference between sUAS images and observer data was the higher resolution of macroalgae in the observer data. While overall macroalgal species richness in seagrass beds is much lower than in the rocky intertidal in Alaska, epiphytic macroalgae on seagrasses are often delicate and cryptic species that are difficult to distinguish on an image. For reasons similar to those discussed for rocky intertidal habitat, the limited resolution of sUAS imagery prohibited identification of these delicate species in seagrass, and the ground camera imagery proved more reliable for detecting these epiphytic macroalgal species. As seagrass system functioning depends heavily on seagrass-epiphyte interactions, the detection of epiphytes may be important to monitoring. For example, epiphytes are vital to nutrient recycling in the system when they take up a majority of nutrients released from seagrass leaves that would otherwise be diluted and lost from the benthic system (McRoy and Goering, 1974; Penhale and Thayer, 1980). Epiphytic algae also contribute significantly to the above-ground productivity of seagrass systems (Heijs, 1985), which then feeds into the associated food web (Kitting et al., 1984). Additionally, epiphytic algae contribute significantly to the overall diversity in seagrass beds, a factor tied to resilience against perturbations (Blake and Duffy, 2010; Duffy, 2006; Duffy et al., 2015). Therefore, the lack of detection of epiphytic algae using sUAS images could be a significant hindrance in using the method when seagrass monitoring goals are associated with those functions.

Seagrass cover itself was not significantly different between sUAS images and observer data (Figure 7). This is a very promising indication of sUASs usefulness for monitoring programs where the goal is to assess seagrass cover over large spatial scales. Seagrasses are foundation organisms that harbor a rich diversity of associated species, many of which are of commercial interest (Johnson et al., 2003). In Alaska, seagrasses also serve as spawning substrate for herring (Haegele and Schweigert, 1985) and provide an important nursery function for this important forage fish, which has experienced significant declines and little recovery after the 1989 *Exxon Valdez* oil spill in Prince William Sound and exposure to other stressors (Carls et al., 2002). Thus, reliably assessing seagrass cover itself is ecologically valuable. We successfully used sUAS images to create distribution maps of seagrass cover over a much larger scale than is feasible by observers on the ground. The maps demonstrate that the size of a seagrass bed can be reliably determined because the fairly sharp transition from seagrass cover to no cover was clearly recognizable. In addition, it was possible to gain an understanding of the small-scale variability and patchiness of seagrass cover, even in the densest region of the bed.

CONCLUSION

The use of sUASs in intertidal monitoring was assessed for a rocky intertidal system and an intertidal seagrass system in the northern Gulf of Alaska. The low resolution of the sUAS imagery created problems in reliably identifying many taxa to species. Some of these shortfalls could be remedied by using higher resolution cameras and an sUAS system that can carry the larger payload that a higher resolution camera may require, if necessary. Lower sUAS flight altitudes would also help improve image resolution; however, this can be challenging on beaches with large boulders or other flight-path obstacles. Still, the value of using sUASs over the more traditional monitoring method of observer surveys remains dependent on the goals of a monitoring program. Programs with questions that can be addressed by a lower taxonomic resolution than observers produce could benefit greatly from the sUAS approach, mostly because of the much larger spatial extent that can be covered during a single low tide period. Our approach of assessing large-scale distribution patterns of seagrass provides an example where the coarse taxonomic resolution of sUAS images was sufficient to yield valuable results. Similar uses could be found for the rocky intertidal; for example, focusing on key taxa such as rockweed (*Fucus* sp.).

Whether or not the sUAS approach is more cost effective and logistically easier must be determined for each application and depends on the specific logistical situation. For example, in more urban areas, sUAS use requires permits that can be difficult to obtain and that may require a licensed pilot. However, such limitations may become easier to overcome with the increased use and application of sUAS systems in monitoring science. Considerable time is needed for the sUAS image analysis when done individually by researchers. Time may be optimized by using automated imaging systems that can either 1) accurately calculate area of recognizable taxa/categories, 2) be trained to identify a library of images of common taxa, or 3) use spectral properties of the organisms in the image to automatically identify organism groups (Pech et al., 2004). Therefore, while we obtained mixed results for the applicability of sUASs in the rocky intertidal and seagrass bed in our study, we have also shown that sUASs can be a valuable tool in monitoring and are likely to become an important tool in monitoring and ocean observing in the future (Lomax et al., 2005). More testing of sUAS use in various systems, and the optimization of camera resolution to flight height, will lay the groundwork for more routine applications.

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