Evaluation of Color Imagery and Direct Referencing for Mapping Submersed Aquatic Vegetation in Chesapeake Bay

Final Report

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David J. Wilcox, Robert J. Orth, Jennifer R. Whiting, Anna K. Kenne, Amy L. Owens, Leah S. Nagey

The Virginia Institute of Marine Science
School of Marine Science, College of William and Mary
Gloucester Point, Virginia 23062

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Executive Summary

The VIMS Annual Submersed Aquatic Vegetation (SAV) Monitoring Program has used black and white aerial photography to map SAV in Chesapeake Bay each year from 1984 to the present, with the exception of 1988. In 2008, VIMS initiated a pilot project to address two potential enhancements identified by a recent external program review: color film and direct referencing technology. Simultaneous color and black and white imagery was captured for three regions. In addition, GPS/inertial mapping unit (IMU) direct referencing data was acquired for two of the regions.

The film type comparison identified some locations where either the color or black and white imagery supported a better delineation of SAV beds; however in most areas the two film types provided similar results. Overall, SAV area interpreted in the Bay regions from the two film types differed by 3% or less. The spatial accuracy of the orthophotography created with only GPS/IMU data was approximately the same as the orthophotography created with manual aerial triangulation. However, processing time was much less. GPS/IMU data could reduce the time needed to create orthophotography by more than 50 days.

As a result of the reduced processing time and similar positional accuracy identified by this study, it was decided to cover the additional cost of GPS/IMU data for the 2009 project. With little obvious benefit offsetting the additional cost and processing time associated with color film, black and white film will continue to be used.

The single most important factor in accurately capturing the abundance and distribution of SAV with aerial photography is the timing of the imagery. Marginal improvements associated with additional spectral data and advanced processing methods are not able to resolve SAV that is completely obscured by turbidity, sun glint, deep water, or waves due to poor timing of the acquisition.

Introduction

The Chesapeake Bay supports a variety of species of submersed aquatic vegetation, from *Zostera marina* in the lower bay to a collection of freshwater species in the upper bay and tributaries (Figure 1, Orth et al. 2009). In the late 1970s, analysis of aerial photography conducted at VIMS documented an unprecedented decline in submersed aquatic vegetation in Chesapeake Bay and suggested a direct link with declining water quality in the Bay (Orth & Moore, Chesapeake Bay: An unprecedented decline in submerged, 1983). Recognizing the importance of SAV as both a key indicator of water quality conditions and a provider of ecological services that are critical to the health of the Bay (Dennison, et al., 1993), VIMS initiated an annual SAV monitoring program in 1984 with funding from a variety of sources including the EPA Bay Program, state management agencies, and private funds. The goal of the program is to monitor the distribution

Figure 1. SAV distribution in Chesapeake Bay

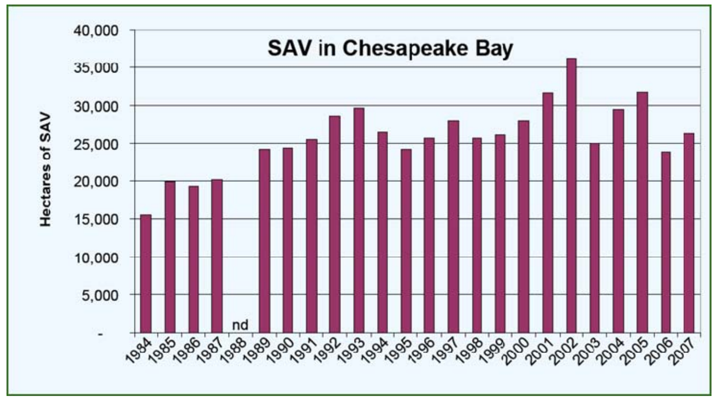

Figure 2. SAV area trends in Chesapeake Bay

and abundance of SAV in the Bay and its tributaries each year as part of the effort to monitor success of Bay cleanup (Orth, Wilcox, Whiting, Nagey, Owens, & Kenne, 2009). The most effective available technology is used to achieve this goal, while ensuring that the annual assessment is consistent with the long-term record of SAV trends in the region.

Total SAV abundance in Chesapeake Bay and its tributaries reflects local patterns in the many SAV species populating the region. The VIMS monitoring program recorded a recovery through the mid 1990s, representing a resurgence of high salinity species from declines in the early 1970s (Figure 2). Though the Bay total has been fairly stable since 1993, there are strong regional differences that appear to be driven by species characteristics and local water quality conditions. After 1993, however, accelerating increases in low-salinity species masked decreases in high-salinity species. Fluctuating abundance of medium-salinity species mostly contributed to inter-annual variability, except in 2002 when a dramatic expansion of widgeon grass drove the bay-wide total to its maximum.

The VIMS Annual SAV Monitoring Program has used black and white aerial photography to map SAV in Chesapeake Bay each year from 1984 to the present, with the exception of 1988. Over this time period, VIMS has kept pace with the rapid development of GIS hardware and software and has closely monitored the evolution of new technology for acquiring imagery. From 1984 to 1987, color imagery was evaluated for all or a portion of the Bay, but in 1989 the program returned to black and white film due to the lower cost and lack of obvious benefits of color film. In 2001, the program implemented soft-copy photogrammetry and aerial triangulation to scan and digitally process the images into a series of orthophoto mosaics. This eliminated the need for physical maps and digitizing of manually interpreted polygons.

New technology has been cautiously adopted by the Annual SAV Monitoring Program, making

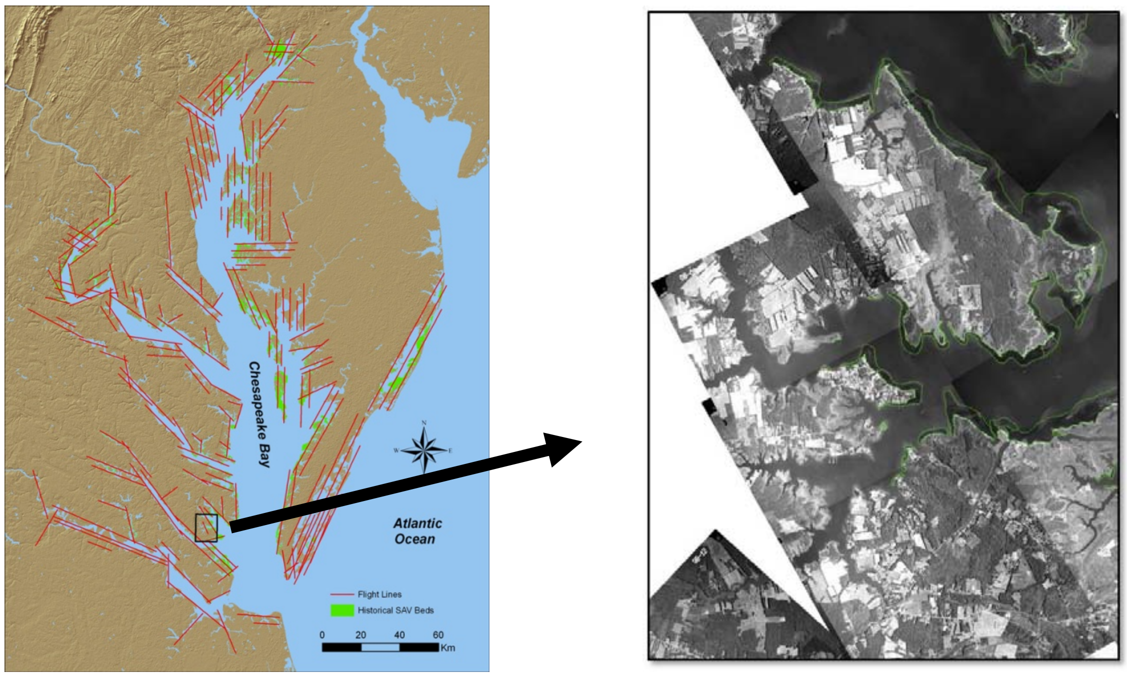

Figure 3. Aerial flight lines used to monitor SAV in Chesapeake Bay

sure that potential benefits associated with a change in basic methodology are carefully weighed against any adverse effects on the continuity of the dataset and any costs associated with implementing the change. Each new tool must be fully evaluated and compared with existing protocols to ensure that recorded changes in SAV abundance are due to actual changes in the natural resource and not due to changes in technology.

A total of 173 flightlines, which cover approximately 3,800 kilometers and include over 2,000 exposures, are acquired over Chesapeake Bay each year (Figure 3). The aerial photography is captured at an altitude of approximately 12,000 ft and is acquired on the small number of clear weather days that also meet the requirements for optimum SAV delineation. It is critical to time the flights during the peak growing season of the SAV species known to occur in each area of the Bay and when the key physical factors are met. These factors are considered when scheduling acquisition (Figure 4a):

It is important to capture areas with a large tidal range or low water clarity at close to low tide (Figure 4b). By restricting imagery to within 90 minutes of low tide and carefully tracking both the predicted and actual tide levels from real-time sensors (e.g., http://tidesonline.nos.noaa.gov), optimal tide levels can be targeted.

To ensure optimum water penetration and minimize surface glint the sun angle is kept between 20° and 40°. If the sun is higher than 40˚ above the horizon, a larger portion of the light is reflected directly towards the sensor, creating sun glint. If the sun drops below 20˚, not enough light penetrates the water surface to expose benthic features (Figure 4c).

Cloud cover can range from dense low-level clouds that completely obscure features to high-level thin clouds and haze that reduce available light and slightly blur SAV signatures (Figure 4d). Clear, haze-free days greatly improve SAV imagery.

Since excess wind can increase turbidity and create surface waves, flights are targeted when surface winds are less than 10 mph. A surface wind speed that is greater than 10 mph can create surface waves that distort the water surface and enhance sun glint. In addition, excess wind can resuspend sediments and degrade water clarity (Figure 4e). Aviation weather data and real-time sensors (e.g., tidesonline.nos.noaa.gov) are used to evaluate conditions.

Turbidity is monitored using all available observations, including real-time monitors, satellite imagery, and observers on the ground to verify that there is sufficient water clarity for SAV delineation (Figure 4f). Many areas of the Bay can remain turbid for long periods of time. Satellite imagery (e.g., rapidfire.sci.gsfc.nasa.gov) and real-time sensors (e.g., www.vecos.org, http://mddnr.chesapeakebay.net/eyesonthebay) can help determine the impacts of weather events on turbidity; however, current field observations remain the best source of water clarity information.

Along with physical and biological factors, security issues are another critical component in photo acquisition. Increased security since the events of September 11, 2001 has made it more

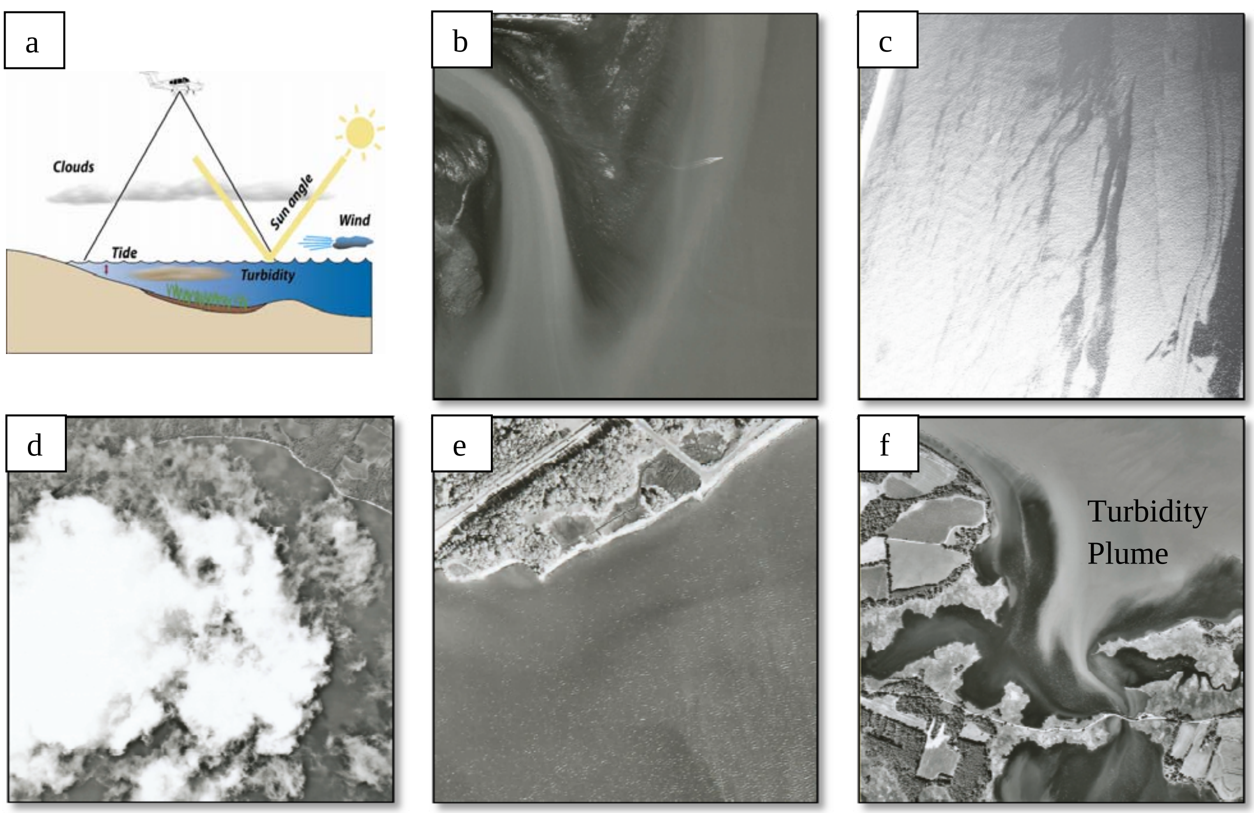

Figure 4. Factors affecting acquisition: a) Conceptual diagram b) Tide Level c) Sun Angle d) Cloud Cover e) Wind Speed f) Turbidity

difficult to acquire imagery of some portions of the Bay. In addition to receiving permission to fly one area in the northern Bay, a security officer is required to be on board the aircraft. The officer maintains control of the film and censors the prints and scans used for SAV mapping. Ideal conditions are not easy to predict and often must be assessed immediately before the flight. Therefore, it is critical that a properly configured aircraft is kept available during each potential acquisition window.

Prints are created immediately after acquisition and mailed overnight to VIMS for evaluation. At VIMS, the prints are inspected on a light table and evaluated to make sure that the imagery is suitable for SAV delineation.

The negatives, containing SAV signatures with sufficient adjacent frames to generate an accurate aerial triangulation model, are scanned with a photogrammetric scanner at 41.6 microns. The resulting digital scans are processed using the ERDAS Leica Photogrammetry Suite (ERDAS, Atlanta GA) image processing system to orthographically correct the individual flight lines using a bundle block solution, correcting for any shifts due to the camera position and the terrain (Figure 5). Camera lens calibration data is matched to the image location of fiducial points to define the interior camera model. Control points from USGS DOQQ images provide exterior control, which is enhanced by a large number of image-matching tie points produced automatically by the software. The exterior and interior models are combined with a 30 m resolution digital elevation model (DEM) from the USGS National Elevation Dataset (NED) to produce an orthophoto for each aerial photograph.

The orthophotographs that cover each USGS 7.5 minute quadrangle are adjusted to uniform brightness and contrast and are mosaicked together using the ERDAS Imagine Mosaic Tool to produce a one-meter resolution quad-sized mosaic. Hard cutlines are used to clearly define the

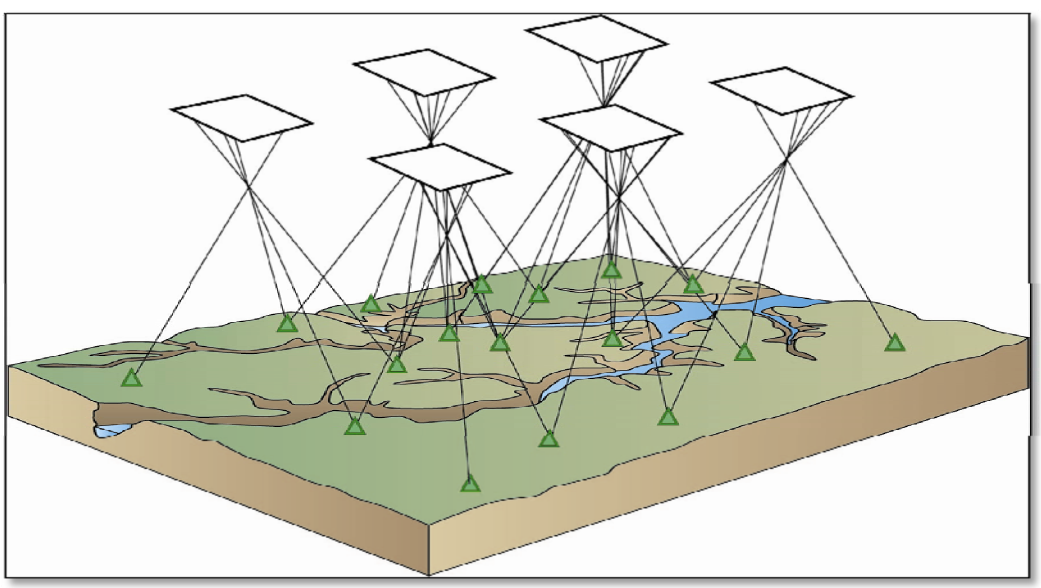

Figure 5. Aerial triangulation bundle block solution

edge of each photo frame since “feathering” to gradually combine the intensity values from adjacent frames in a transition zone can blur features and create hidden artifacts.

The photointerpreters delineate SAV beds from the mosaics using ESRI ArcGIS software. Once a quadrangle is photointerpreted it is reviewed with the QA Coordinator, edits are made and then the quadrangle is passed on to the QA Managers for final review following our quality assurance procedures.

In 2006, the US EPA contracted with Science Applications International Corporation (SAIC) to perform a comprehensive review of the VIMS annual SAV monitoring program (SAIC, 2006). As a result of this review, five technologies were discussed as potential changes to the program: 1) GPS/inertial mapping unit (IMU) equipped flights 2) Color photography 3) Digital photography 4) Stereo images and 5) Spectral imaging. Of these, the first three were identified as higher priorities for evaluation, and the current study reviews two of these priority technologies (GPS/IMU equipped flights and color photography).

In the first component of this study we compare two film types for use in Chesapeake Bay. Other monitoring programs have noted that color film can improve the ability to discriminate between some benthic features and between dark features and deep water. (Finkbeiner, Stevenson, & Seaman, 2001; Sam S. Jackson, 2006). They also noted that the color imagery can be helpful in identifying features in unfamiliar areas.

The second component of the study tests the benefits associated with GPS/IMU technology. This direct referencing technology is becoming more accessible at a reduced cost. It is expected to require less time to process, thereby reducing labor hours and permitting faster production of orthophotography. The additional data might also improve the positional accuracy of the final SAV data (SAIC, 2006).

Study Objectives

- To evaluate the advantages and disadvantages of color imagery versus black & white imagery for mapping SAV
- To evaluate the costs and benefits of direct referencing (GPS/IMU) technology

Methods

Recognizing potential benefits, VIMS initiated a pilot project to address these two study objectives: comparing film types and evaluating the use of direct referencing technology. Simultaneous color and black and white imagery was captured for three regions: Potomac, Mobjack, and Coastal (Figure 6), one dominated by freshwater species and two dominated by seagrass species. In addition, GPS/IMU direct referencing data was acquired for the camera containing the color film for two of the areas.

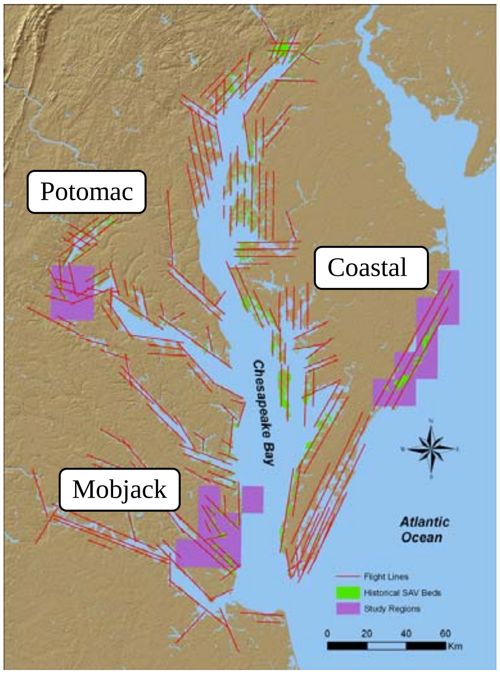

Figure 6. The location of the three study regions used for this project

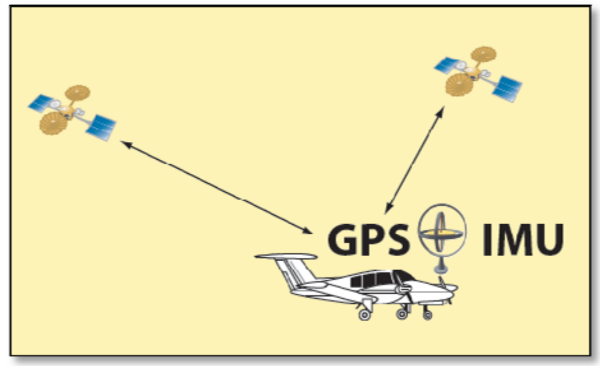

Figure 7. GPS/IMU technology combines an inertial measurement unit (IMU) with a geographic positioning system (GPS) to determine and record the position and orientation of the camera as images are acquired

The three study regions were captured by an aircraft equipped with dual frame cameras. One of these cameras was loaded with Agfa Pan 80 B&W film and the other with AGFA X-100 color film. Potomac, the smallest region with four quadrangles, was selected to cover a portion of the Potomac River that supports a variety of freshwater SAV species. Mobjack, the largest of the regions, covers seven USGS quadrangles stretching from the James River to Mobjack Bay. This region is dominated by the higher salinity seagrass species *Zostera marina* (eelgrass) and *Ruppia maritima* (widgeon grass). The Coastal region, composed of eight quadrangles, covers a portion of the Virginia outer coastal bays that are higher in salinity and support *Zostera* and *Ruppia*, but also has a diverse assemblage of algae.

The plan was to capture all three regions with an aircraft equipped with a Novatel DL dual frequency GPS and an Applanix Phalanx IMU attached to the aerial camera containing color film (Figure 7). However, there were issues with the GPS/IMU acquisition. In the Potomac, our contractor had a mechanical issue with the plane and the tandem cameras had to be moved at the last minute without time to calibrate the GPS/IMU. In the Coastal Bays, the GPS/IMU was out of calibration, so we were not able to use the data. Therefore, the Mobjack was the only region with usable GPS/IMU data.

For Mobjack, an aerial triangulation model was computed by one operator using manually selected control points from USGS DOQQ imagery and by a second operator using data from the GPS/IMU. Processing time was tracked and independent check points were selected for the two sets of orthophotographs to estimate positional error.

Two experienced photointerpreters independently used ArcMap (ESRI, Redlands CA) to delineate SAV polygons for each region. These raw data were archived and then compared to the 2008 final dataset that was produced using our customary quality assurance procedures on only the black and white imagery.

All associated expenditures and processing times were recorded along with any advantages or disadvantages associated with these two technologies as they are applied to the Annual SAV Monitoring Program. Each step of the project was carefully studied to estimate differences in processing time, total cost, and interpretation accuracy.

Results

Evaluation of Film types

The raw data mapped from each film type is listed in Table 1. These results are compared to the final 2008 area which is mapped solely from the black and white imagery that undergoes our customary rigorous quality control procedures. The percent change of the film type versus the final 2008 area is also listed in Table 1.

The final product for the coastal region was notably different than either of the pilot project results, due to additional black and white imagery that was acquired after the pilot project was complete. In addition, the earlier imagery for this region contained a significant amount of algae that complicated the interpretation. The difference in the estimate of total SAV area for the two film types in the Potomac and Mobjack regions was within 3% of final mapped area total (Table 1). This confirms the interpreter’s subjective conclusion that the color imagery did not notably modify the digitized boundaries.

After the interpreters were finished mapping the regions, they reviewed both sets of imagery for locations where the SAV signature was more clearly visible on one film type that the other. In a few locations, particularly in the fresher portion of the Bay, SAV was clearer on the color film. However, in the majority of the Bay, the film types were roughly equivalent (Figure 8).

In evaluating the two film types, we found that the color imagery took approximately one and a half more time for the computer to process due to the larger size of the image files. For the entire project, this results in an estimate of about 16 hours to convert and orthorectify the color images versus 6 hours to process the black and white images.

Table 1. Raw data area comparison by film type and interpreter relative to the final area reported. The maps completed by Interpreter A are shaded in gray. Those completed by Interpreter B are not shaded. Areas are in hectares.

	Raw Data			Raw Data versus Final			
Quad	**B&W**	**Color**	**Final**	**B&W**		**Color**	
55	1,189.79	1,154.73	1,177.83	11.96	(1%)	-23.10	(-2%)
56	55.12	52.58	55.26	-0.14	(0%)	-2.68	(-5%)
64	152.25	144.68	154.40	-2.14	(-1%)	-9.72	(-6%)
65	40.46	33.22	41.50	-1.05	(-3%)	-8.28	(-20%)
Potomac	1,437.62	1,385.21	1,428.99	8.63	(1%)	-43.78	(-3%)
122	421.26	404.92	415.58	5.68	(1%)	-10.66	(-3%)
131	962.31	962.46	939.81	22.50	(2%)	22.65	(2%)
132	1,035.00	1,056.77	1,028.83	6.17	(1%)	27.94	(3%)
139	0.21	0.13	0.21	0.00	(0%)	-0.08	(-38%)
140	300.77	263.85	282.71	18.06	(6%)	-18.86	(-7%)
141	622.59	578.19	615.38	7.21	(1%)	-37.18	(-6%)
178	0.34	0.34	0.30	0.03	(11%)	0.04	(12%)
Mobjack	3,342.48	3,266.67	3,282.83	59.65	(2%)	-16.16	(0%)
166	273.40	252.89	361.58	-88.19	(-24%)	-108.69	(-30%)
167	239.01	204.66	201.54	37.47	(19%)	3.13	(2%)
168	203.17	141.05	145.05	58.13	(40%)	-3.99	(-3%)
170	1,886.15	1,767.32	1,685.91	200.24	(12%)	81.41	(5%)
172	766.17	706.65	600.82	165.34	(28%)	105.83	(18%)
173	605.12	420.53	347.77	257.35	(74%)	72.75	(21%)
174	246.96	198.32	145.09	101.86	(70%)	53.23	(37%)
175	1,209.15	1,195.46	928.58	280.57	(30%)	266.88	(29%)
Coastal	5,429.13	4,886.88	4,416.35	1,012.78	(23%)	470.54	(11%)
Total	10,209.23	9,538.76	9,128.08	1,081.15	(12%)	410.68	(4%)

Evaluation of Direct Referencing

Although there were some problems with the GPS/IMU acquisition, in the one region where it was successfully captured, we had positive results. The direct referencing data reduced the time necessary to orthorectify the photography. Each frame of the color imagery with GPS/IMU data required an average of 8 minutes to process, one sixth of the 44 minutes that it took to rectify each black & white frame using aerial triangulation (Table 2). Applied to the entire Bay, this results in an estimate of 9 days to process all 588 frames used in 2008 with GPS/IMU data versus 54 days without GPS/IMU data.

Since good GPS/IMU data was available for only one region in 2008 and that region was captured in a single flight, an assessment of positional accuracy is somewhat limited. A better assessment of the positional accuracy of the orthophotography generated using GPS/IMU data is possible using data from the 2009 monitoring project. In 2009, almost all the aerial photography was acquired with GPS/IMU data. Therefore, we can compare the checkpoint RMSE of the 2009 dataset that was processed using GPS/IMU data with the checkpoint RMSE of the 2008 dataset that was processed using aerial triangulation without GPS/IMU data (Table 3). The positional accuracy of the two methods is similar. Both sets of orthophotography had an RMSE value between approximately 1-5 m with a mean value of about 3-4 m. However, the checkpoints for the manual aerial triangulation were taken from the same USGS DOQQs used to generate ground

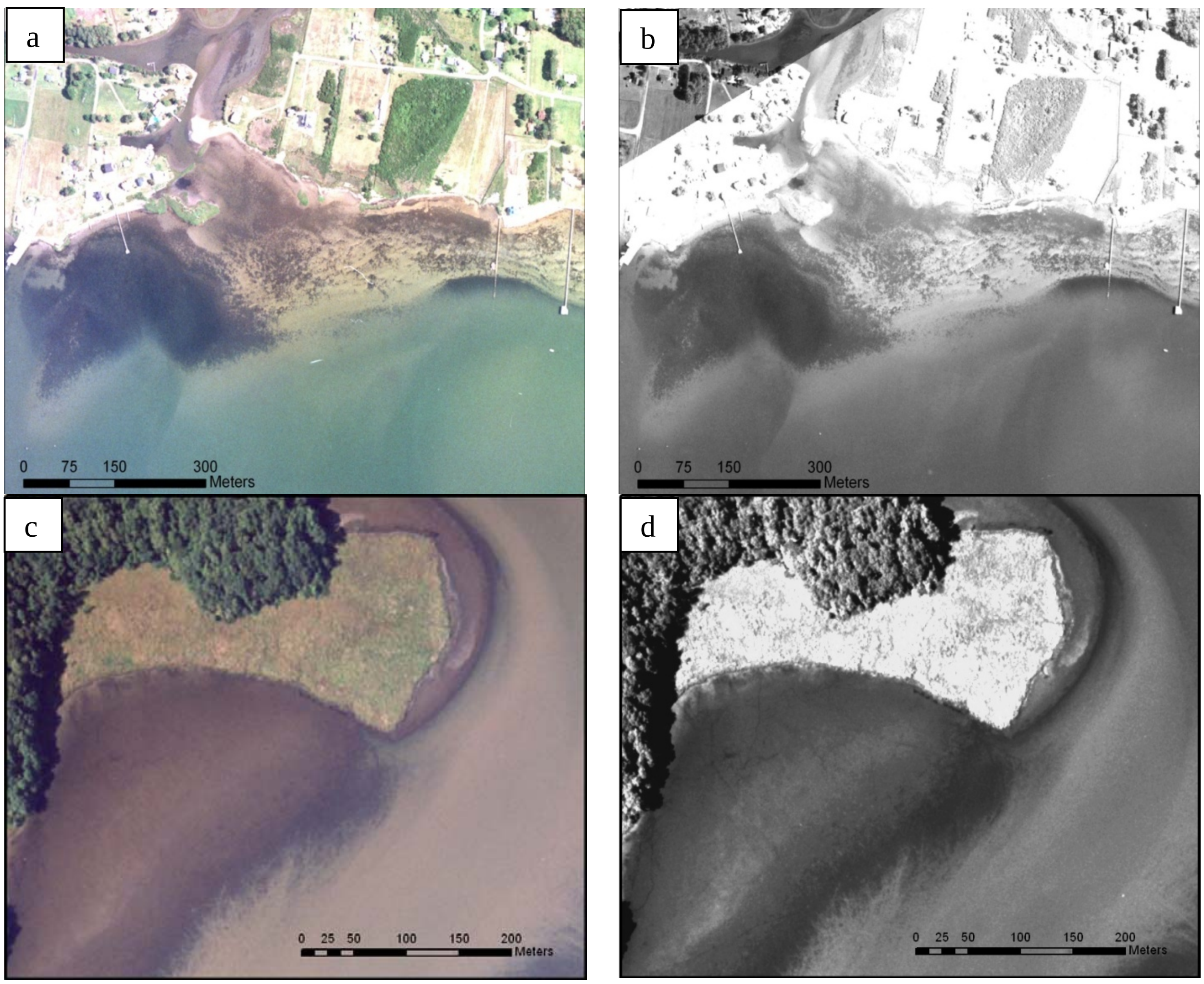

Figure 8. Comparison of film type: a) color image acquired over the north shore of the lower York River b) black and white image of the same area c) color image acquired over Accokeek Creek off Potomac Creek in the Middle Potomac River d) black and white image of the same area

control points for triangulation. Therefore the RMSE value for the two methods may be more similar.

Table 2. Imagery processing time with GPS/IMU vs. manual aerial triangulation

Flightline	Number of Frames	GPS/IMU Time (Hour:Mins)	Manual Time (Hour:Mins)
91	4	1:13	2:00
91A	3	0:32	1:44
92	8	0:51	5:44
92A	3	0:30	2:26
93	6	0:45	5:20
94	3	0:27	1:59
95	3	0:24	1:29
96	11	1:00	7:50
96A	7	0:42	6:10
97	9	0:57	6:51
Total	57	7:21	17:33
	Average per frame	0:08	0:44
		Number of frames scanned in 2008	588
	Estimated number of hours to process the entire Bay	75.82	428.62
	Estimated number of days to process the entire Bay	9.48	53.58

Table 3. Comparison of horizontal checkpoint RMSE for the blocks processed in 2009 with GPS/IMU data and the blocks processed in 2008 using manual aerial triangulation

	Number of Blocks	Checkpoint Horizontal RMSE (m)		
		Min	**Mean**	**Max**
With GPS/IMU (2009)	108	1.66	3.78	5.59
Manual Aerial Triangulation (2008)	151	0.66	2.73	5.29

Conclusions and Discussion

While color imagery may have significant advantages in other regions, for the majority of the Chesapeake Bay, it does not notably improve the visual delineation of SAV. Spectral analysis and enhancement may provide some benefit, but evaluation of these processes was outside the scope of this project. It is expected that costs associated with color film and digital color imagery will continue to decline. At some point it will probably be incorporated into the monitoring program, but until that happens, black and white film will continue to be used.

The single most important factor in accurately aerially capturing the abundance and distribution of SAV is the timing of the imagery. SAV signature completely obscured by turbidity, sun glint, deep water, or waves due to poor timing of the acquisition cannot be overcome by marginal improvements in spectral resolution or enhanced processing. We found that direct referencing data can reduce the time required to produce orthophotography with no loss of positional accuracy. We were impressed with the time advantage of the GPS/IMU data and have added that to the Annual SAV Mapping Program. It is currently more expensive to acquire GPS/IMU data since the additional annual cost (approximately $29,000) is more than the savings in personnel time (44 days at approximately $7,600). However, these costs are based on the actual current rates available from our aerial contractor working within the constraints of a multi-year contract and may differ from the GPS/IMU rates of other vendors.

Potential enhancements will be reviewed in the future including the advantages and disadvantages of satellite-based imagery, digital aerial imagery, multispectral and hyperspectral imagery, and advanced image processing techniques. As each of these are considered, the results will be evaluated and used to guide the SAV monitoring project with careful consideration to maintaining consistency within this key multi-decadal SAV monitoring dataset.

Acknowledgements

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