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Advancements with UAVs for analyzing transportation infrastructure and mapping invasive aquatic plants

Colin Brooks

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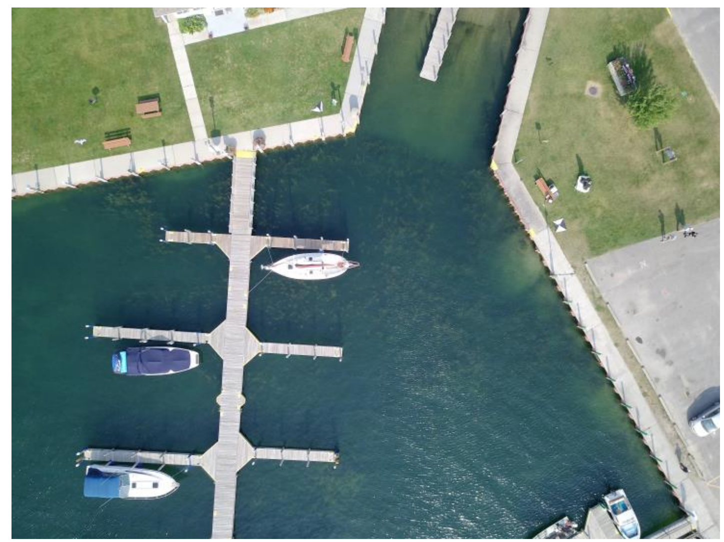

GIS Users Meeting, Nov. 1, 2018, Lansing

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Augmenting Bridge Inspections through UAS-enabled Multi-Sensor Data Collections

Team lead:

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Project colleagues:

Michigan Technological University: Thomas Oommen, Tim Havens, Tess Ahlborn, Amlan Mukherjee, Kuilin Zhang, Rick Dobson, David Banach, Ben Hart, Sam Aden, Rudiger Escobar-Wolf, Nick Marion

SSI, Inc: Andrew Semenchuk, Jeff Bartlett

Project funding provided by:

Michigan Department of Transportation (2016-0067/Auth.1: OR15-139)

Program Manager: Steve Cook, Research Mgr: André Clover

Michigan Tech Research Institute

UAV Platforms

- Multiple platforms have been tested
  - Focus on flexible, lower cost platforms
- Bergen Hexacopter & Quad-8
  - Price: $4,500 to $6,200
  - Flight time: 20 min
  - Payload: up to 4.5 kg (~10 lbs)
  - Hexacopter first tested on USDOT OST-R CRS&SI project on Unpaved Road Assessment project http://www.mtri.org/unpaved/
- Aerostat / Tethered Blimp
  - Test system: $1500 (higher winds version ~$4,500)
- Imaging small quadcopters (<$1600)
  - DJI Phantom 3 Advanced
  - 3D Robotics IRIS+
  - Mariner, Splash2 (waterproof)
  - DJI Mavic Pro
- Micro-UAS quadcopters
  - Confined space imaging
  - <$500

Optical Sensor
for Structure-from-Motion (SfM) photogrammetry

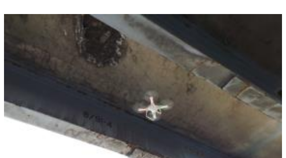
- Nikon D800, D810 – full-sized (FX) sensor, 36.3 MP, 4 fps - $3,000
- 50mm prime lens - $700
- Collect stereo overlapping imagery to create cm-resolution 3D surfaces
  - Structure from Motion (SfM) photogrammetry
  - AgiSoft Photoscan
  - MTRI SfM software workflow
- Demonstrated on USDOT unpaved roads project (CRS&SI – C.Singh)

Creating 3D data from overlapping images

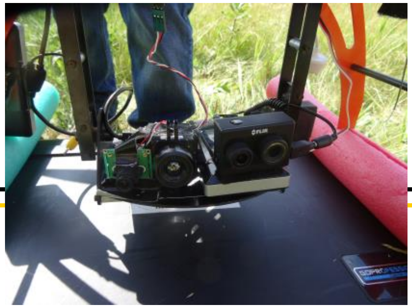
Optical sensor: small quadcopter cameras for basemap & corridor imaging, bridge components, & traffic video

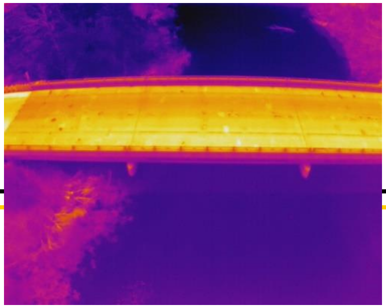
- Small cameras on board DJI Mavic Pro & Phantom small quadcopters + Mariner series
- Provide 12-20 mp images & up to 4K video
- Useful for making basemaps of sites
- Imaging fascia & undersides of bridges
- Recording traffic video for analysis





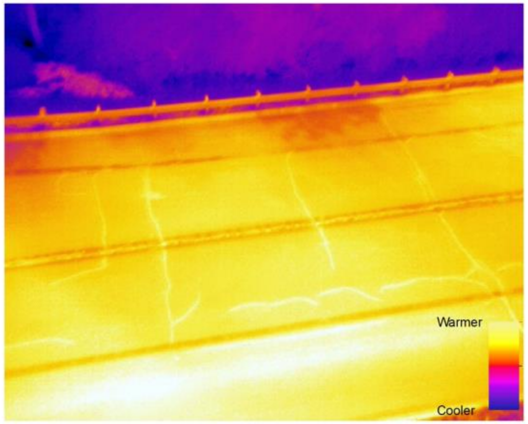
Thermal Sensors

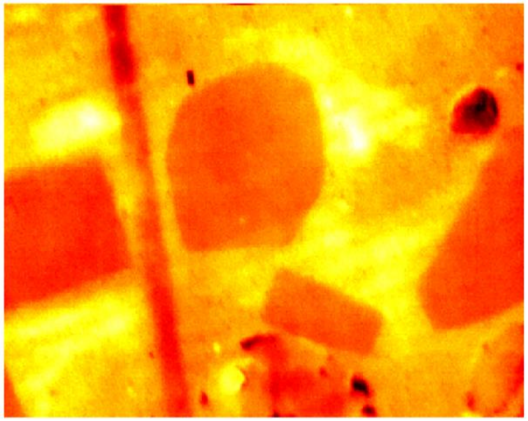




Sensitive to 7.5 - 13.5 µm, within 5% of reading

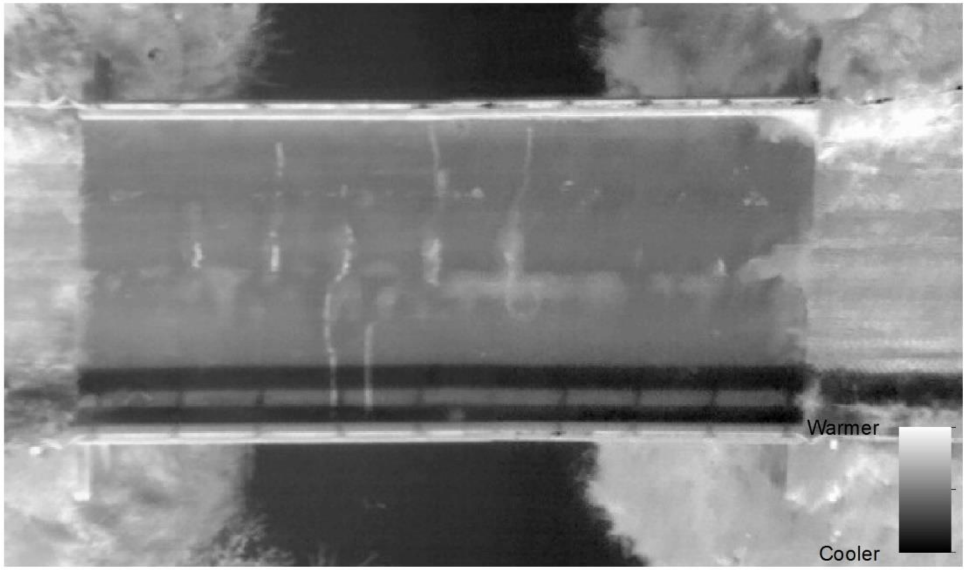
FLIR Tau 2 – 640 x 512 sensor





FLIR Vue Pro & Pro R -640 x 512 sensor (Pro R - Radiometric version, ~$5400)

FLIR Duo – 160x120, $999



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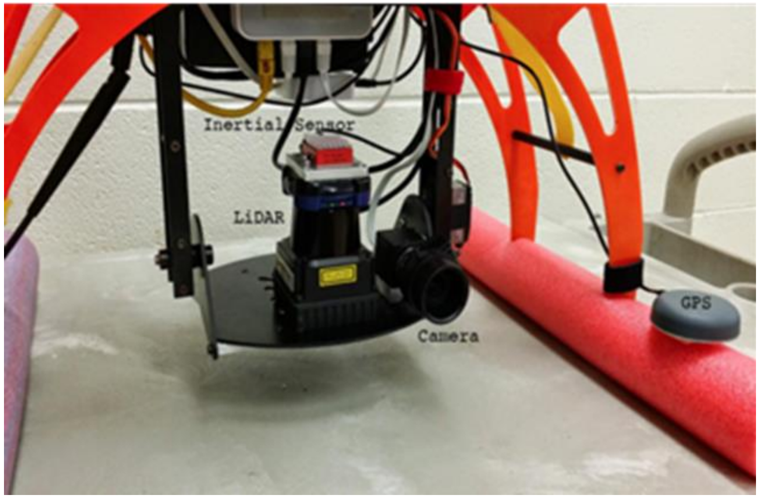
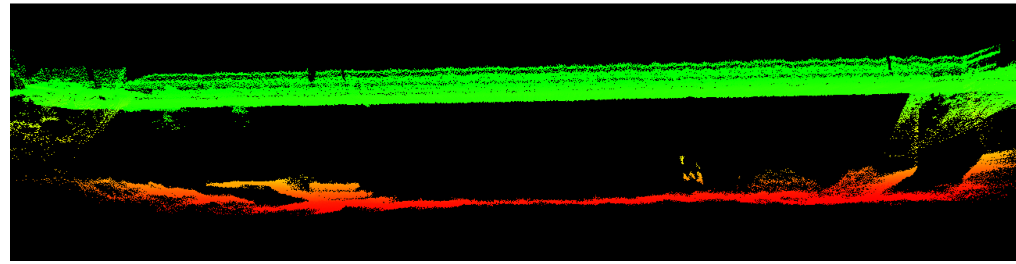
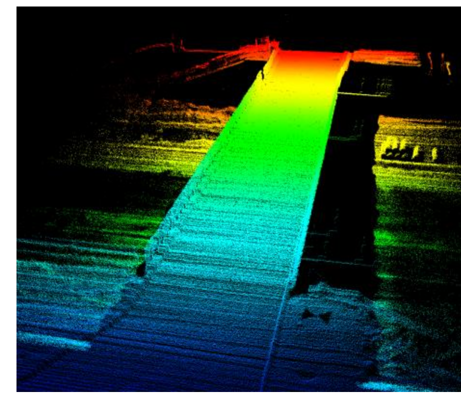
LiDAR for 3D bridge & road models



Hokuyo UTM-30LX LiDAR

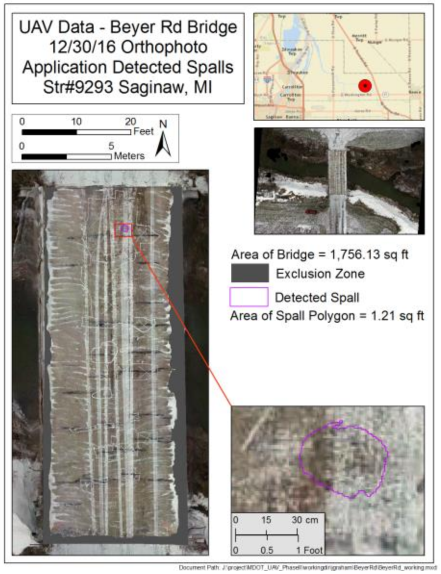
Velodyne LiDAR Puck (~$8k – now $4k)

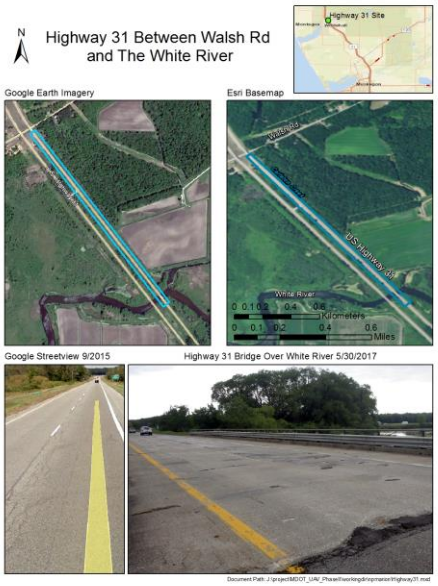


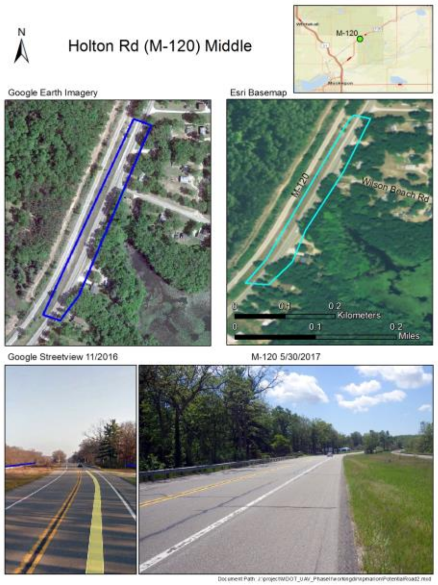


Example sensing data sets & results

- Focus on corridor & bridge data in s. Michigan
- Collected data from 5 bridges, 2 highway corridors in Phase II project; 2 bridges in Phase I
- Demonstrated both overhead (nadir) and offset (oblique) data collections
  - – UAS deployment more practical with oblique data collections
  - – Current FAA rules do not allow operation of UAS over moving traffic, people (Part 107)
  - – Waiver process possible

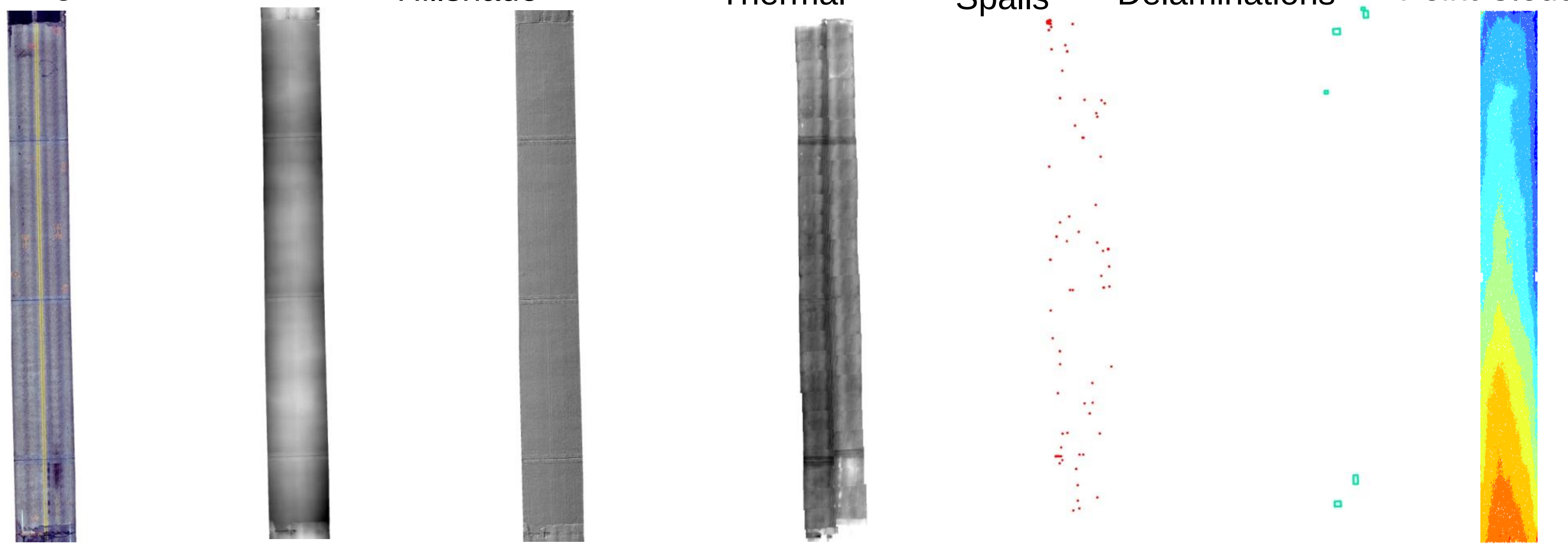




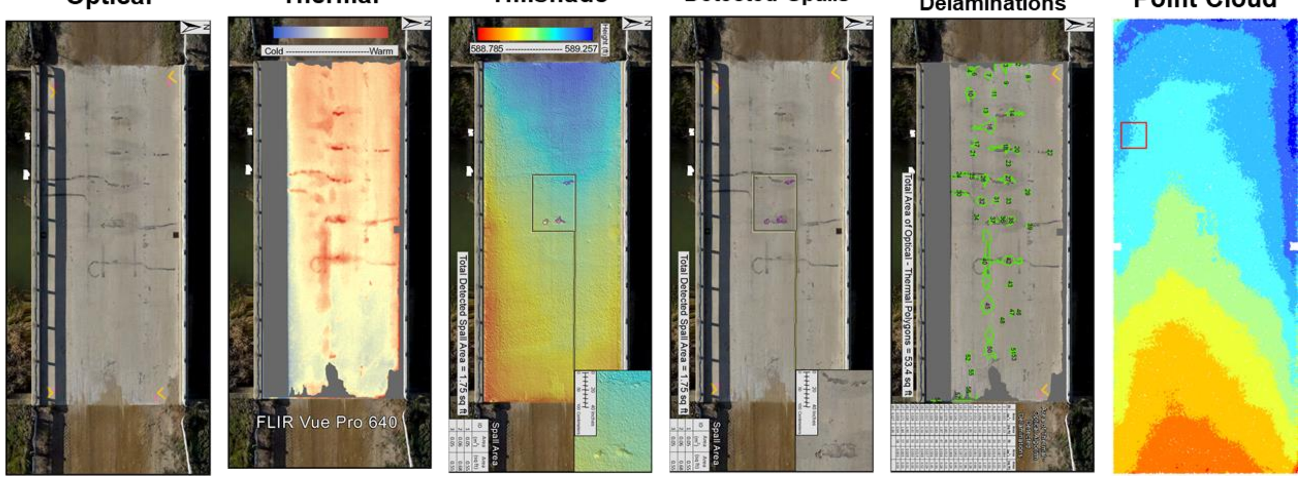


Seven standard geospatial outputs for UAS sensing of bridge decks

Orthoimage | DEM | Hillshade | Thermal | Spalls | Delaminations | Point Cloud

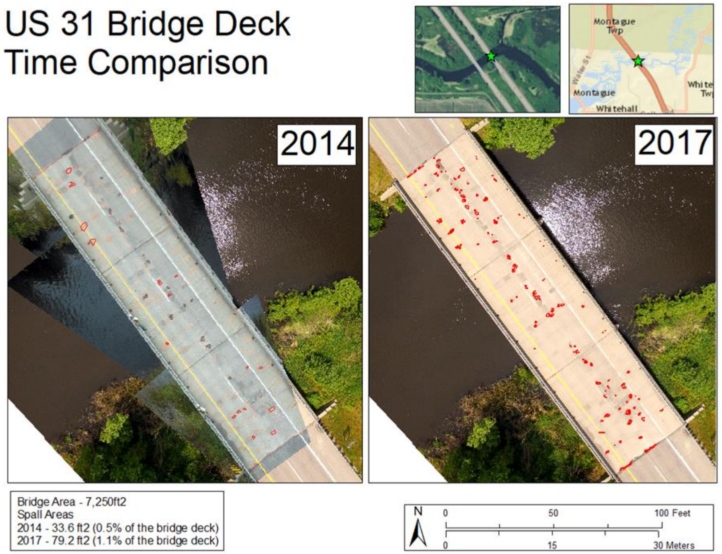


Optical | Thermal | Hillshade | Detected Spalls | Detected Delaminations | Point Cloud



Automated spall detection

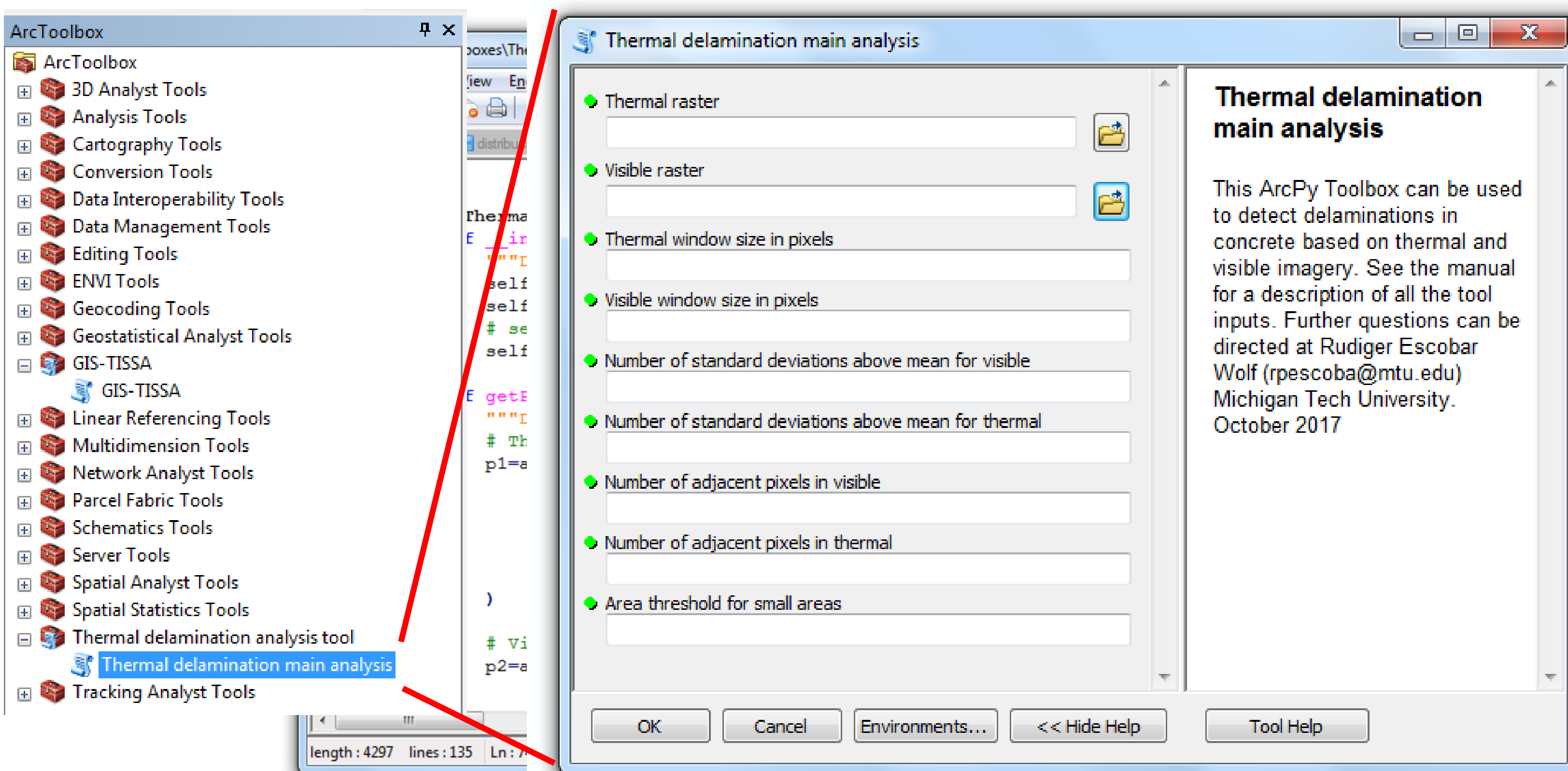
- Automated spall detection algorithm (developed by Brooks, Dobson, Aden, Graham)
- Applied to high-resolution 3D elevation model (DEM) of bridges created from UAS images
- Merriman East: 4.4% spalled (150.0 ft^2)
- US-31/White River: 79.2 ft^2 (1.1%) spalling in 2017 vs. 33.6 ft^2 (0.5%) in 2014



Thermal Algorithm for Delamination Detection

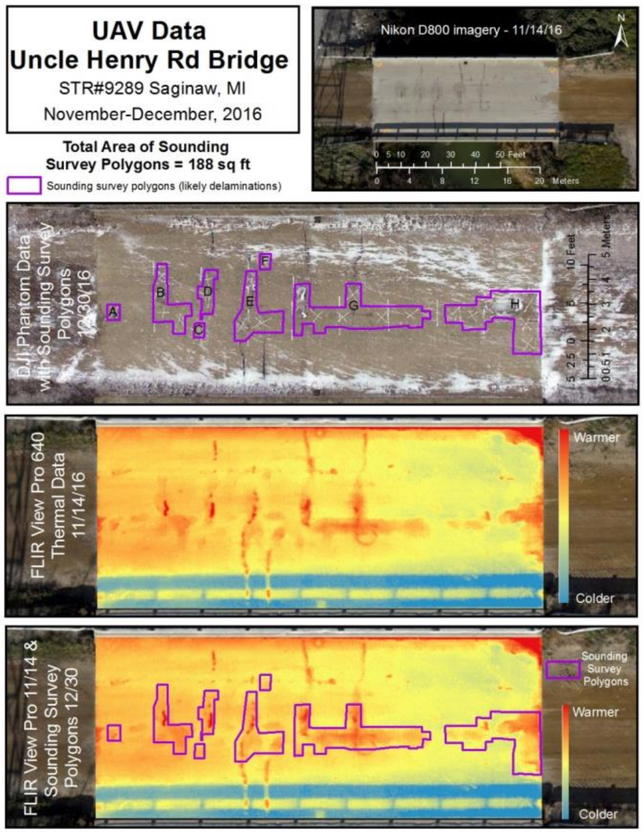
Thermal delamination analysis tool

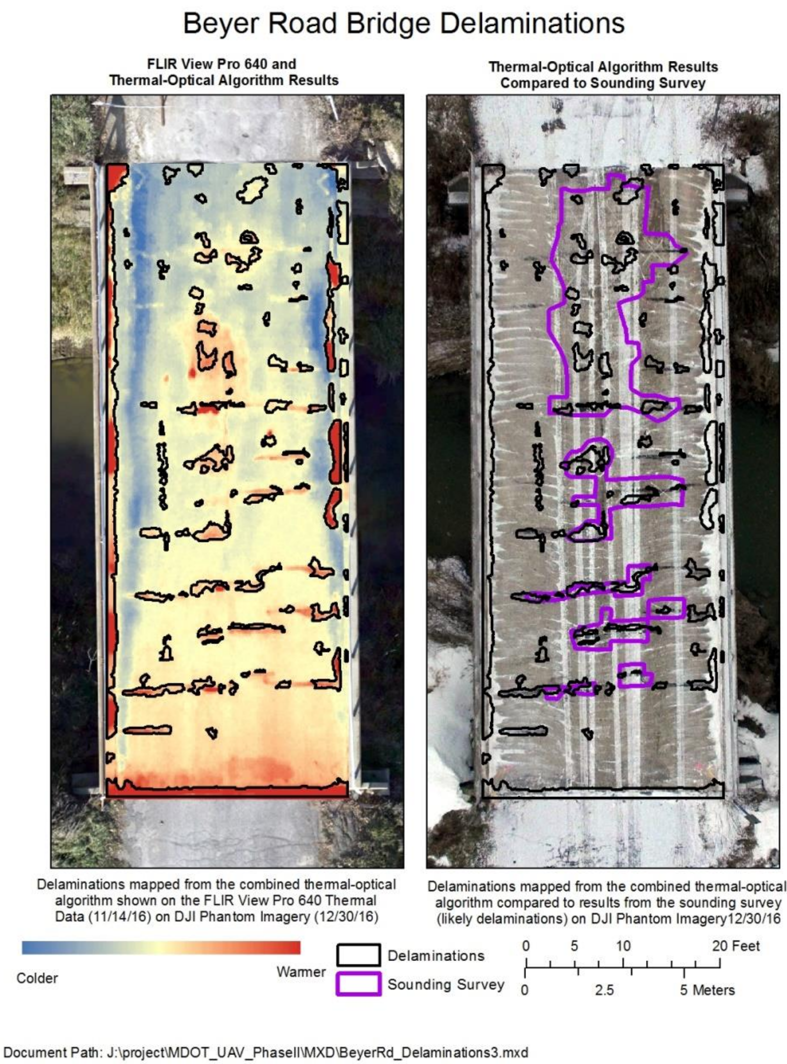
- Developed an ArcPy tool based on the thermal-visible algorithm
- User friendly (i. e. through standard ArcGIS Tool GUI)



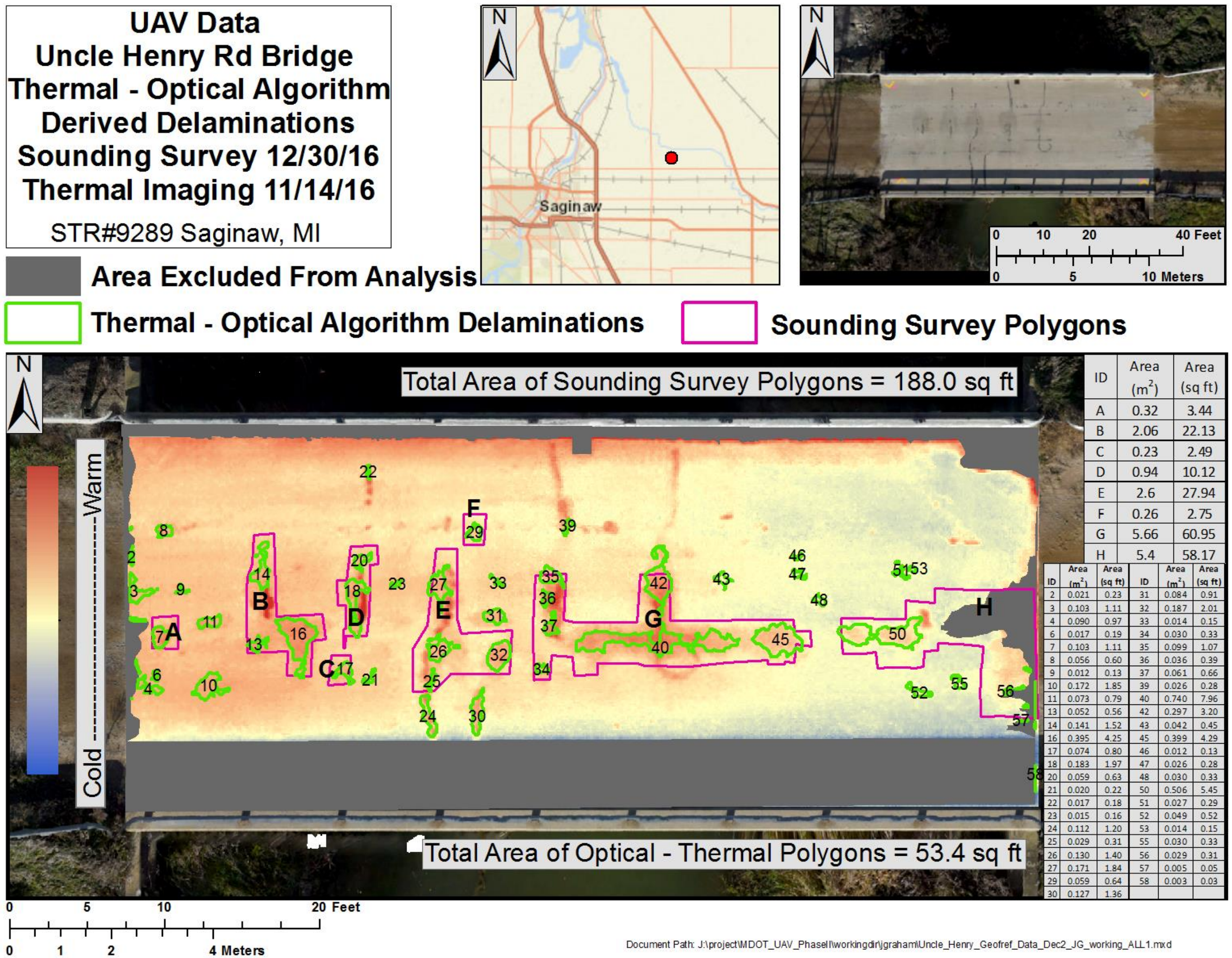
Analyzing thermal results

Compare results to traditional hammer sounding & chain drag methods (NDT)





Quantitative thermal analysis results



ID	Area (m²)	Area (sq ft)
A	0.32	3.44
B	2.06	22.13
C	0.23	2.49
D	0.94	10.12
E	2.6	27.94
F	0.26	2.75
G	5.66	60.95
H	5.4	58.17

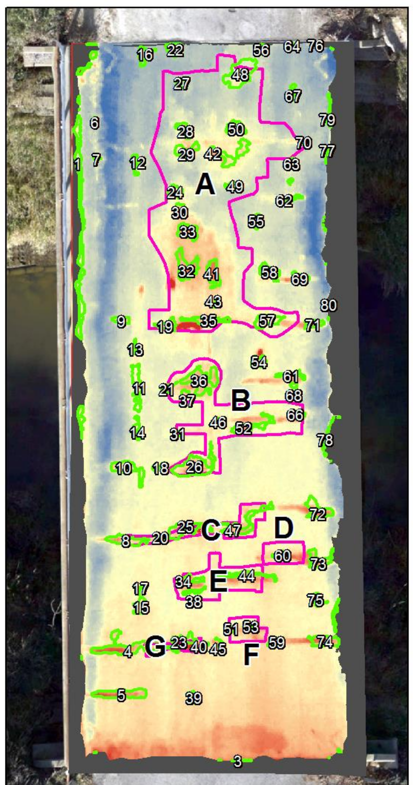
ID	Area (m²)	Area (sq ft)	ID	Area (m²)	Area (sq ft)
2	0.021	0.23	31	0.084	0.91
3	0.103	1.11	32	0.187	2.01
4	0.090	0.97	33	0.014	0.15
6	0.017	0.19	34	0.030	0.33
7	0.103	1.11	35	0.099	1.07
8	0.056	0.60	36	0.036	0.39
9	0.012	0.13	37	0.061	0.66
10	0.172	1.85	39	0.026	0.28
11	0.073	0.79	40	0.740	7.96
13	0.052	0.56	42	0.297	3.20
14	0.141	1.52	43	0.042	0.45
16	0.395	4.25	45	0.399	4.29
17	0.074	0.80	46	0.012	0.13
18	0.183	1.97	47	0.026	0.28
20	0.059	0.63	48	0.030	0.33
21	0.020	0.22	50	0.506	5.45
22	0.017	0.18	51	0.027	0.29
23	0.015	0.16	52	0.049	0.52
24	0.112	1.20	53	0.014	0.15
25	0.029	0.31	55	0.030	0.33
26	0.130	1.40	56	0.029	0.31
27	0.171	1.84	57	0.005	0.05
29	0.059	0.64	58	0.003	0.03
30	0.127	1.36			

Existing thermal method: ASTM D4788 - 03(2013)
Standard Test Method for Detecting Delaminations in Bridge Decks Using Infrared Thermography

Beyer Rd Bridge quantitative results

UAV Data - Beyer Rd Bridge
Sounding Survey 12/30/16
Algorithimic Delaminations
Thermal Data 11/14/16
Str#9293 Saginaw, MI

0 10 20 Feet
0 5 Meters
N



Area of Bridge = 1,756.13 sq ft
Total Area of Sounding Survey Polygons = 313.28 sq ft

Total Area of Delamination Polygons = 92.73 sq ft

Sounding Survey Polygon
Detected Delamination
Exclusion Zone

Warm
Cold

Delamination Polygon Area

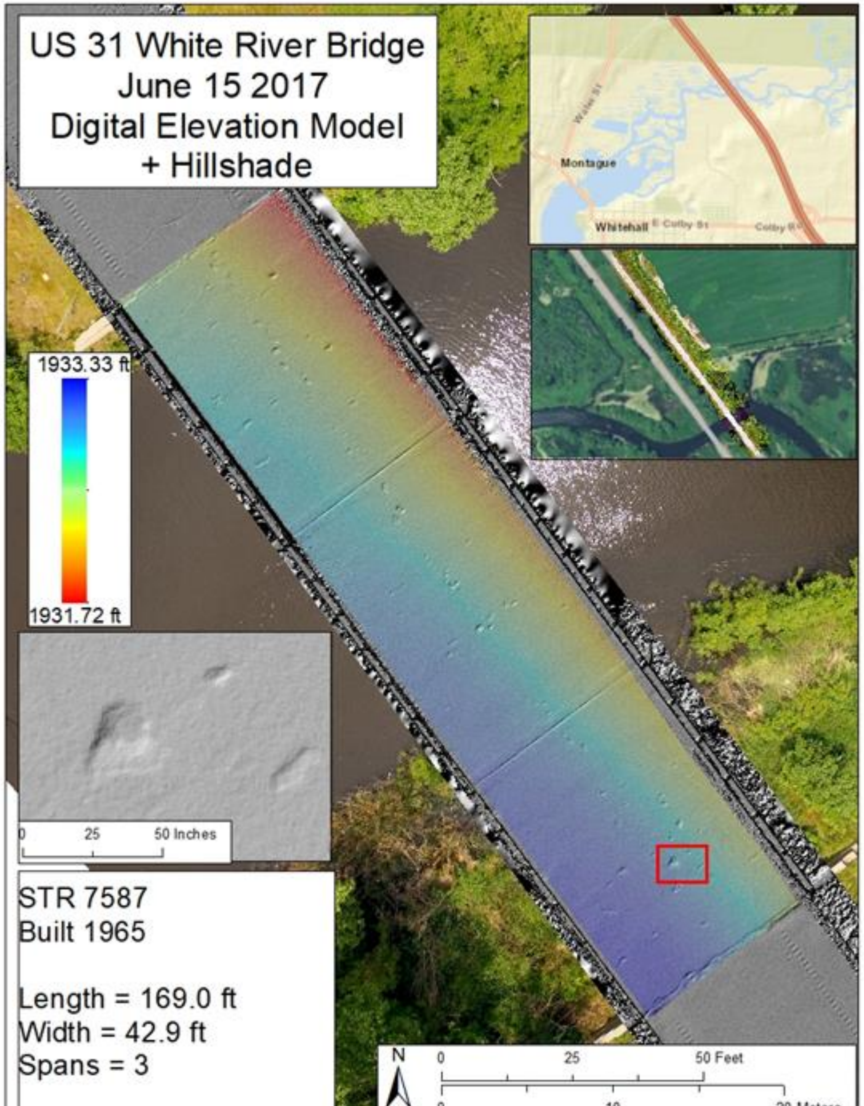
ID	Area (sq ft)	Area (m^2)
1	7.36	0.68
4	4.61	0.43
26	4.55	0.42
48	4.51	0.42
36	3.91	0.36
5	2.96	0.28
32	2.87	0.27
42	2.71	0.25
25	2.64	0.25
47	2.53	0.24
72	2.30	0.21
74	2.25	0.21
10	2.25	0.21
8	2.05	0.19
11	2.05	0.19
Sum of 65 remaining	43.19	4.01

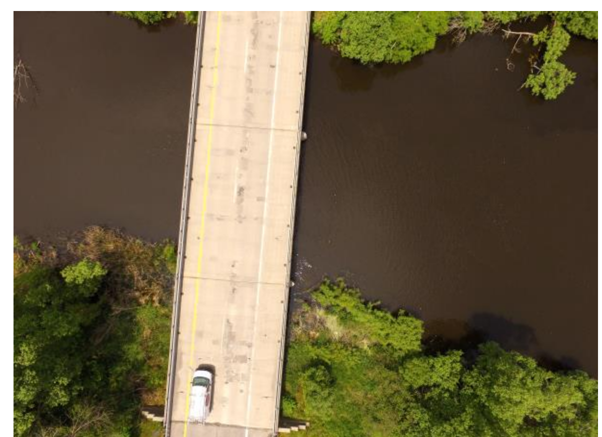
Sounding Survey Polygon Area

ID	Area (sq ft)	Area (m^2)
A	211.2	19.62
B	51.06	4.74
C	14.21	1.32
D	6.93	0.64
E	19.01	1.77
F	6.52	0.61
G	4.39	0.41

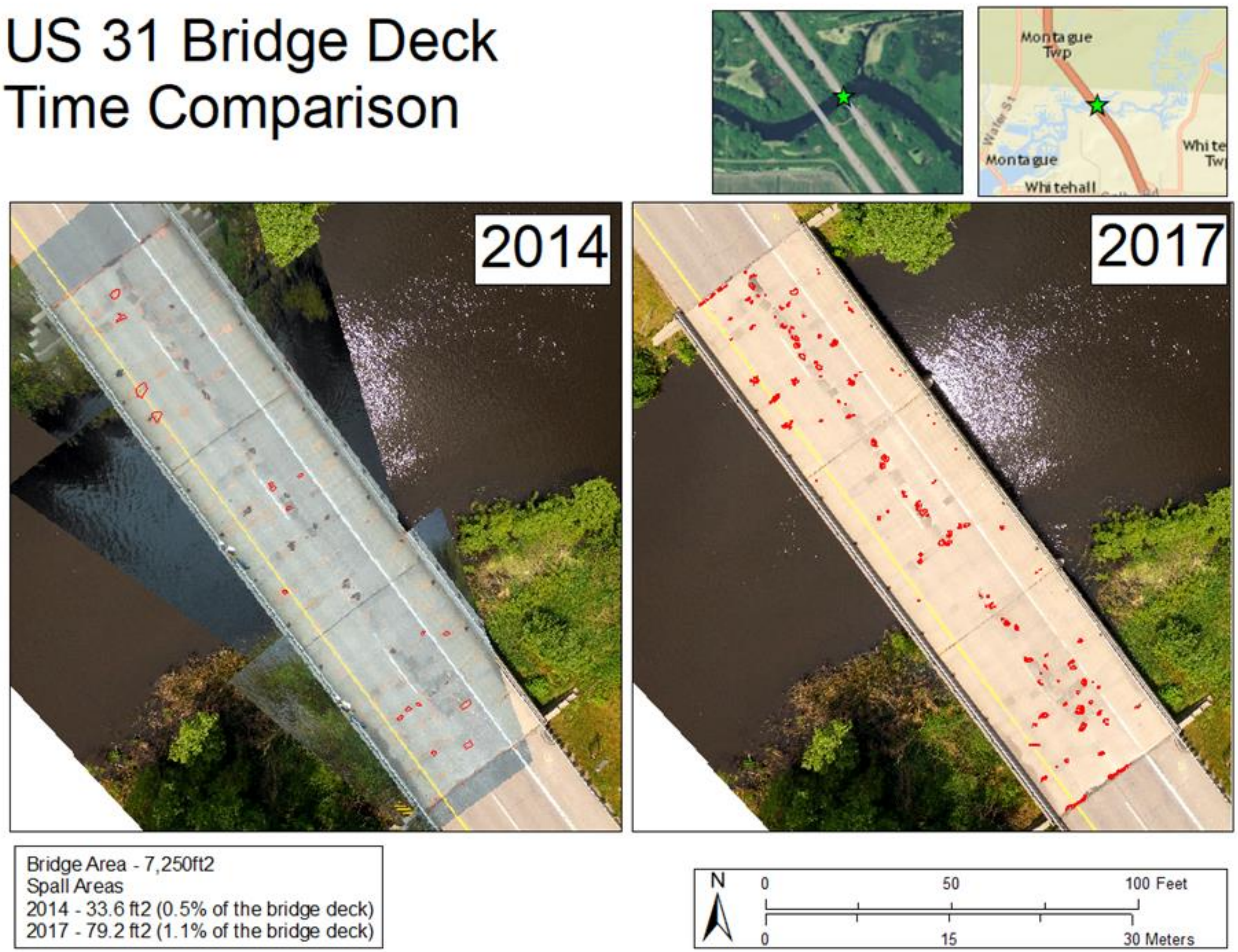
Document Path: J:\project\MDOT_UAV_PhaseII\workingdir\jgraham\BeyerRd\BeyerRd_working.mxd

US-31 White River Bridge & corridor - Nikon D810 DEM + Hillshade

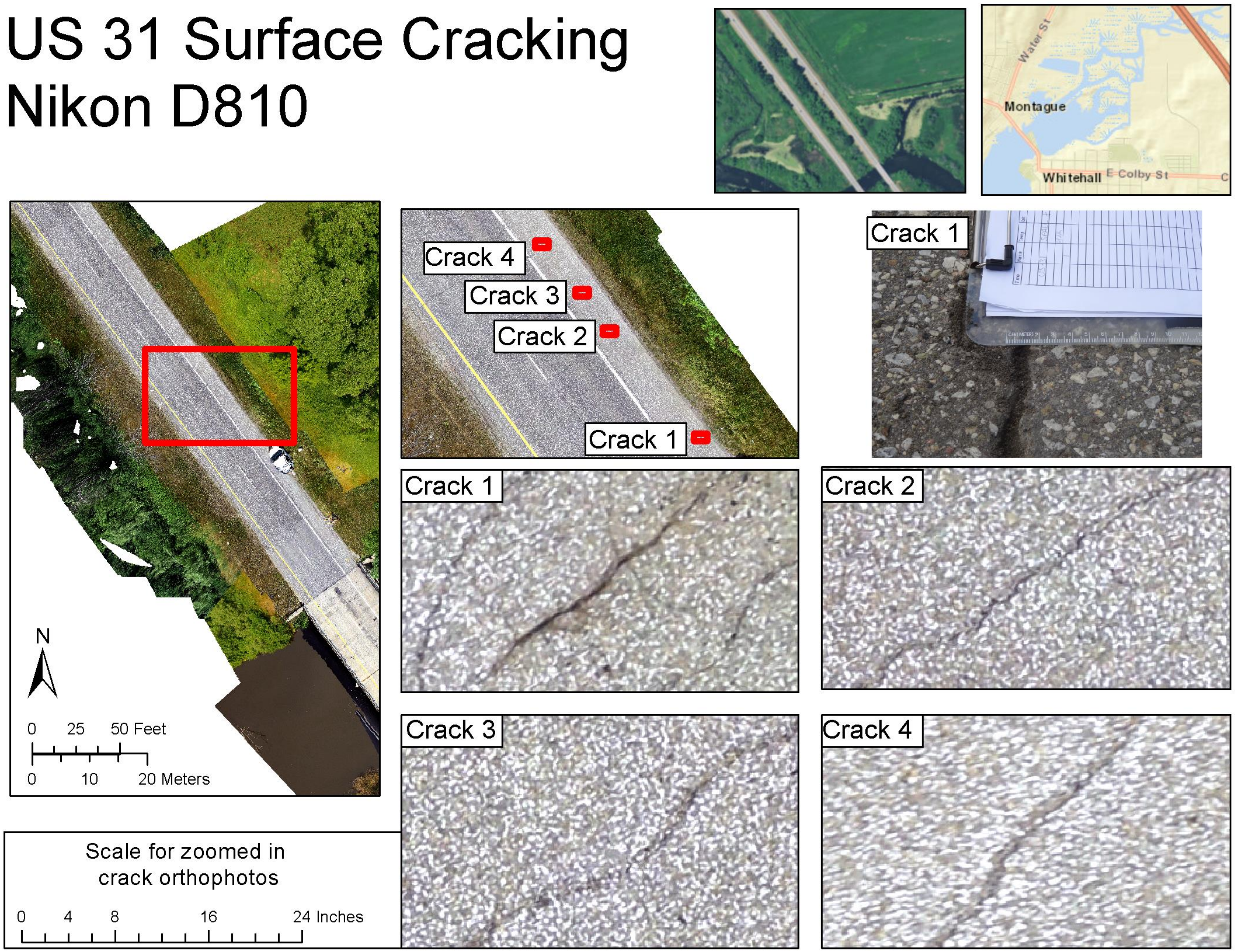




US-31 White River Bridge - Spall Progression

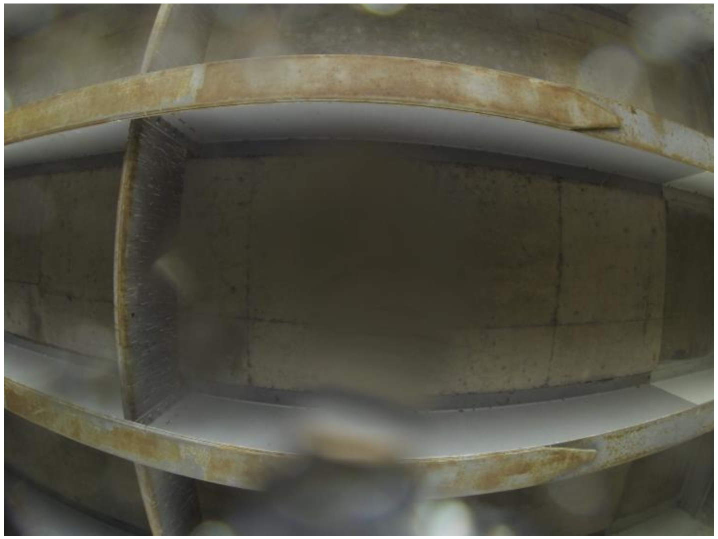


US-31 – crack comparisons (Nikon D810 imagery)



Underside of US-31/White River bridge – Splash2 drone

- Application worked, but Splash2 needs further development



Cost-Benefit Analysis results

- Calculated Net Present Value (NPV) of treatment costs
- UAV-enabled thermal analysis techniques are finding smaller areas of delamination distress than NDT techniques (chain dragging-CD/hammer sounding-HS)
- Better estimation of amounts of distress using UAVs can help lower maintenance costs
  – Repair smaller, more precise areas

Distress: Delamination (sq ft)	NDT Technique	
Bridge	UAV	CD and HS
Uncle Henry Road	53.59 ft^2	188.0
Beyer Road	92.73	313.28

	Net Present Value			
Bridge	Uncle Henry Road		Beyer Road	
NDT Technique	UAV	CD HS	UAV	CD and HS
Condition	Fair	Poor	Fair	Poor
Treatments				
Patching	$10,438	$35,614	$18,061	$61,016
Concrete Overlay	$1,184	$4,152	$2,048	$6,919
Asphaltic concrete overlay without membrane	$447	$1,569	$774	$2,615
Asphaltic concrete overlay with membrane	$723	$3,364	$1,250	$4,224
Deck replacement (new deck with epoxy-coated bars)	$1,337	$4,688	$2,313	$7,813

Patching - $10,438 vs. $35,614 – 70% less

Managing Processed Datasets: Collected vs. final sizes

Site	Optical	Thermal
Beyer Rd.	8 GB (total data collected)	285 MB (total data collected)
	37 MB (merged scene)	120 KB (merged scene)
Uncle Henry	1.72 GB (total data collected)	220 MB (total data collected)
	54 MB (merged scene)	120 KB (merged scene)
Holton Road	25 GB (total data collected)	**Vue Pro** 600 MB (total data collected)
		730 KB (merged scene)
	6 GB (merged scene)	**Vue Pro R** 540 MB (total data collected)
		660 KB (merged scene)

Site	Optical	Thermal
US31 / White River	17 GB (total data collected)	**Vue Pro R – AM** 1 GB (total data collection)
		2.5 MB (merged scene – corridor) 20 KB (merged scene – bridge
	5 GB (merged scene) *70% less space*	**Vue Pro R – PM** 500 MB (total data collection)
		4.5 MB (merged scene – corridor) 25 KB (merged scene – bridge
Gordonville	5.8 GB (total data collected)	315 MB (total data collected)
	64 MB (merged scene)	675 KB (merged scene)

ASPRS & NCHRP Accuracy Statements

Accuracy	HIGH < 0.05 m (< 0.16 ft)	MEDIUM 0.05 to 0.20 m (0.16 to 0.66 ft)	LOW > 0.20 m (> 0.66 ft)
Density	1A	2A	3A
FINE >100 pts/m² (>9 pts/ft²)	• Engineering surveys • Digital terrain modeling • Construction automation/ Machine control • ADA compliance • *Clearances** • *Pavement analysis* • Drainage/Flooding analysis • Virtual, 3D design • CAD models/Baseline data • BIM/BRIM** • Post-construction quality control • As-built/As-is/Repair documentation • Structural inspections	• *Forensics/Accident investigation** • *Historical preservation* • Power line clearance	• Roadway condition assessment (general)
	1B	2B	3B
INTERMEDIATE 30 to 100 pts/m² (3 to 9 pts/ft²)	• Unstable slopes • Landslide assessment	• General mapping • *General measurements* • Driver assistance • Autonomous navigation • Automated/Semi-automatic extraction of signs and other features • Coastal change • *Safety* • Environmental studies	• Asset management • Inventory mapping (e.g., GIS) • Virtual tourism
	1C	2C	3C
COARSE <30 pts/m² (<3 pts/ft²)	• *Quantities (e.g., earthwork)* • Natural terrain mapping	• *Vegetation management*	• Emergency response • Planning • Land use/Zoning • Urban modeling • Traffic congestion/ Parking utilization • Billboard management

*Network accuracies may be relaxed for applications identified in red italics.

**BIM/BRIM: BIM = Building Information Modeling; BRIM = Bridge Information Modeling.

These are on

transportati

New ASPRS Positional Accuracy Standards for Digital Geospatial Data

- **Replaces:**
  - ASPRS Accuracy Standards for Large-Scale Maps (1990)
  - ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data (2004)
- **Developed by:**
  - ASPRS Map Accuracy Standards Working Group, PAD, PDAD and LIDAR joint committee for map accuracy standard update
- **In Final Approved Version**
  - REVISION 7, VERSION 1, Nov. 14, 2014
  - Approved and adopted by ASPRS during the board meeting on Monday Nov. 17, 2014 in Denver during ASPRS 2014 PECORA conference

asprs THE IMAGING & GEOSPATIAL INFORMATION SOCIETY

WOOLPERT

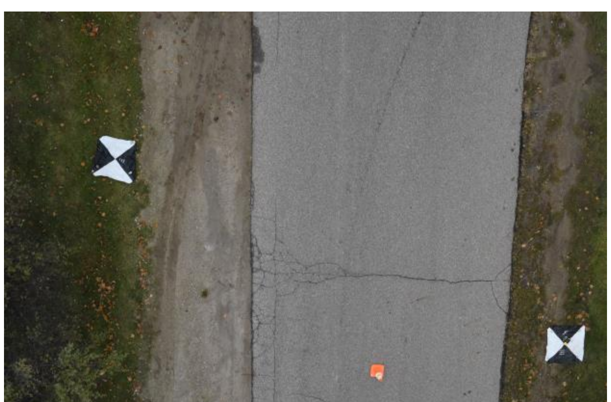
Datasets are documented using both ASPRS and NCHRP accuracy standards.

TABLE 7.1 HORIZONTAL ACCURACY STANDARDS FOR GEOSPATIAL DATA

Horizontal Accuracy Class	Absolute Accuracy			Orthoimagery Mosaic Seamline Mismatch (cm)
	$RMSE_x$ and $RMSE_y$ (cm)	$RMSE_r$ (cm)	Horizontal Accuracy at 95% Confidence Level (cm)	
X-cm	$\leq X$	$\leq 1.414*X$	$\leq 2.448*X$	$\leq 2*X$

TABLE 7.2 VERTICAL ACCURACY STANDARDS FOR DIGITAL ELEVATION DATA

Vertical Accuracy Class	Absolute Accuracy			Relative Accuracy (where applicable)		
	$RMSE_z$ Non-Vegetated (cm)	NVA[1] at 95% Confidence Level (cm)	VVA[2] at 95th Percentile (cm)	Within-Swath Hard Surface Repeatability (Max Diff) (cm)	Swath-to-Swath Non-Vegetated Terrain ($RMSD_z$) (cm)	Swath-to-Swath Non-Vegetated Terrain (Max Diff) (cm)
X-cm	$\leq X$	$\leq 1.96*X$	$\leq 3.00*X$	$\leq 0.60*X$	$\leq 0.80*X$	$\leq 1.60*X$



Metadata

- Written to match Federal Geographic Data Committee - Content Standard for Digital Geospatial Metadata (FGDC CSDGM) standards. ISO 19115 compatible. XML format
- Includes all necessary information; summary, description, accuracy measurements, contact information, etc.

Holton_Nikon_DEM.tif

Raster Dataset

Thumbnail Not Available

Tags

road corridor, DEM, UAV

Summary

This dataset shows the elevation of a section of the Holton Road corridor through optical imagery collected by a unmanned aerial vehicle.

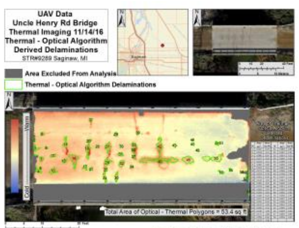
Description

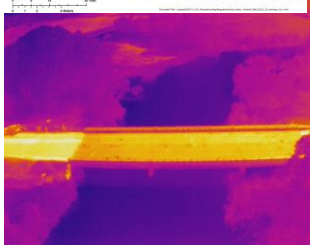
This orthoimage shows the elevation of a portion of the Holton Road (M-120) corridor (near Twin Lakes, Michigan). The imagery that makes up this image was collected onboard of the Bergen Hexacopter, an unmanned aerial vehical (UAV) with a Nikon D810 optical camera and 50mm prime lens. All of the images collected were processed through Agisoft Photoscan, which reconstructed the imagery into a three-dimensional model. This DEM (with 9 mm (0.03 ft) resolution) is an export from Agisoft Photoscan, which has been assigned a Michigan State Plane coordinate system and georeferenced.

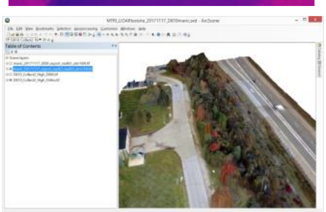
Credits

C. Brooks and J. Graham - Michigan Tech Research Institute

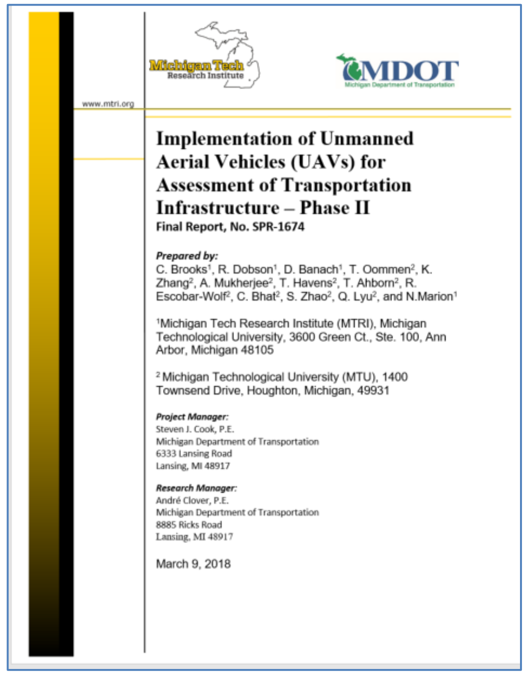
Final Report







https://www.michigan.gov/documents/mdot/SPR-1674_FinalReport_revised_631648_7.pdf



Michigan Tech Research Institute

MDOT
Michigan Department of Transportation

www.mtri.org

Implementation of Unmanned Aerial Vehicles (UAVs) for Assessment of Transportation Infrastructure – Phase II

Final Report, No. SPR-1674

Prepared by:
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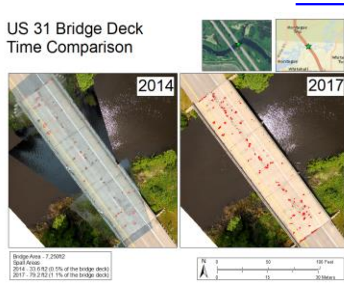
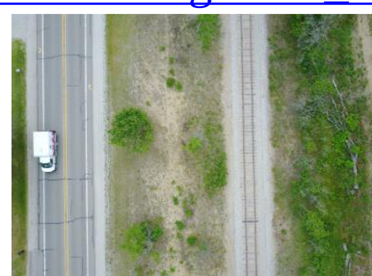
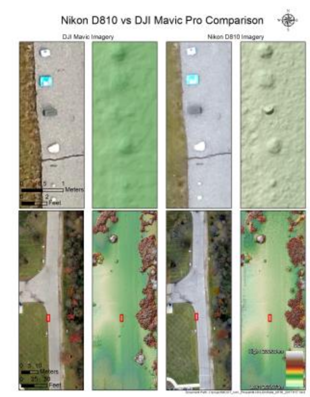
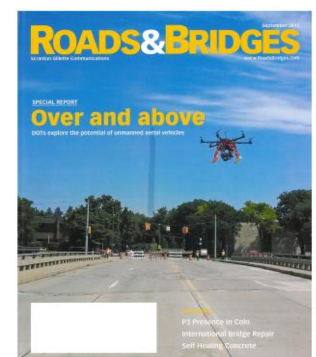
March 9, 2018

www.mtri.org/mdot_uav.html









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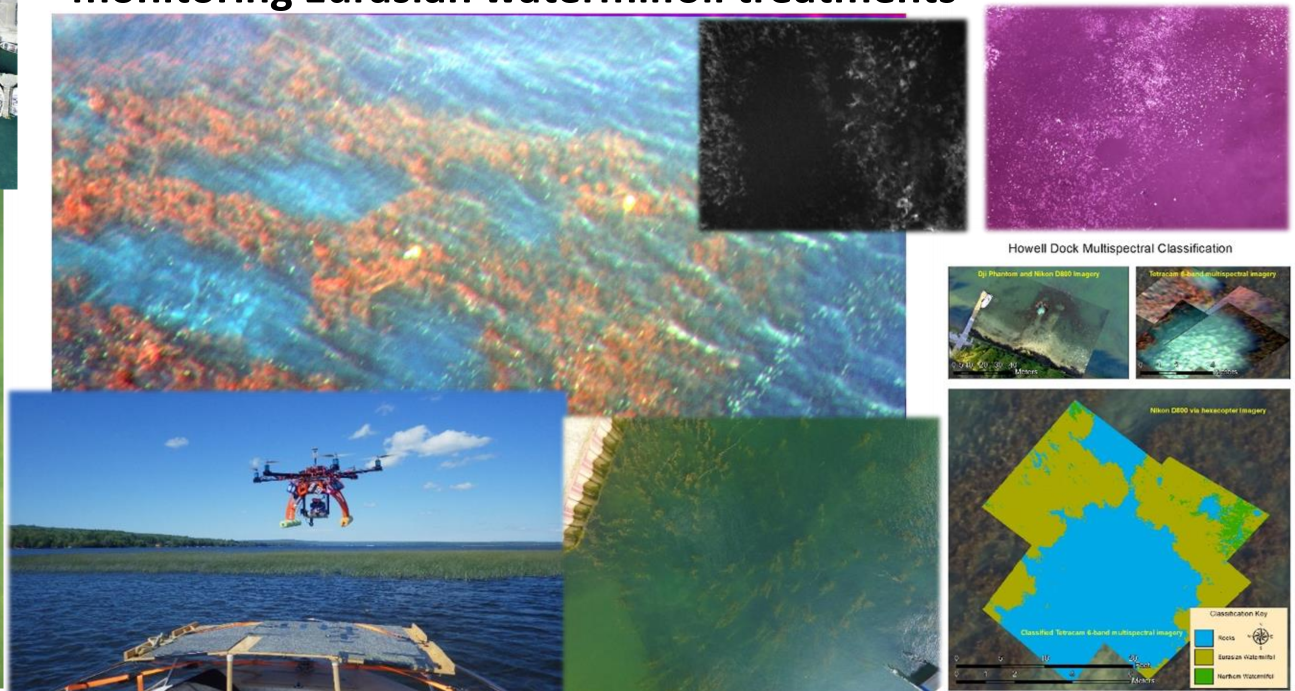
Unmanned aerial system multispectral imagery mapping for monitoring Eurasian watermilfoil treatments



State of Lake Superior 2018, Houghton, MI

Colin Brooks[1,2], Amy Marcarelli[2], Amanda Grimm[1], Casey Huckins[2], Richard Dobson[1], Ryan Van Goethem[2], Robert Smith[3]

1 Michigan Tech Research Institute, Michigan Technological University; 2 Biological Sciences Department, Michigan Technological University; 3 Les Cheneaux Watershed Council

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Great Lakes Research Center Michigan Technological University

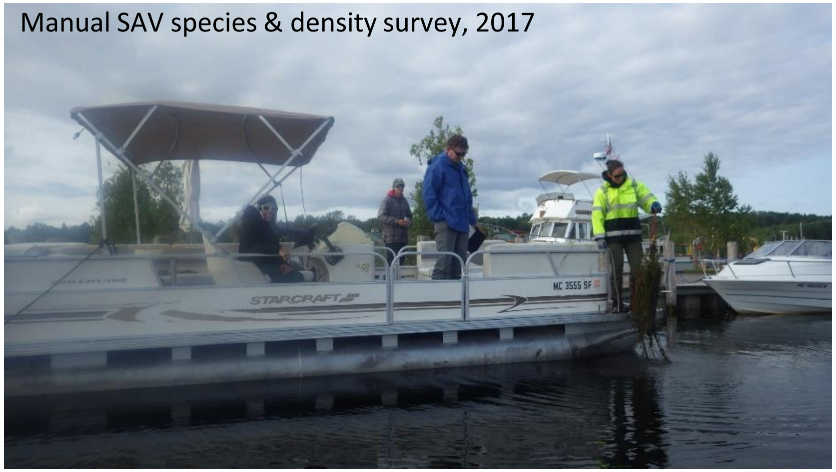
Great Lakes Restoration

Michigan Tech Research Institute

Background: why SAV mapping with UAS?

- There is a need to improve detection and monitoring of submerged aquatic vegetation (SAV), particularly for invasive aquatic plants
- Currently, most management activities rely on ground surveys, typically requiring significant resources and limited in scale
  - Challenging to document change from boat-side surveys
  - Can extend value of boat-based surveys

Great Lakes Invasive Watermilfoil observations.
Source: USGS GLANSIS


Manual SAV species & density survey, 2017

Background: Eurasian watermilfoil

- Eurasian watermilfoil (**EWM**) *Myriophyllum spicatum* and its hybrids, or collectively invasive watermilfoil (**IWM**), can outcompete important native macrophytes, modifying the littoral zone and interfering with boating and recreation
- Millions of $$$ spent on control efforts, often with only short-term relief
- Monitoring options are limited

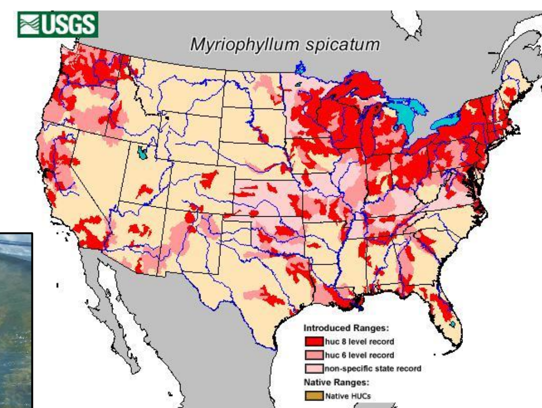


Photo from
http://www.ecy.wa.gov/programs/wq/plants/weeds/milfoil.html

Applied research questions

- Is EWM spectrally distinct from other common aquatic macrophytes of the upper Great Lakes?
  - Create an EWM specific algorithm
- If so, can its distinct spectral features be used to monitor EWM extent before and after treatment efforts from multispectral imagery?
  - Apply algorithm to monitoring treatment effectiveness
  - Understand impacts of different water characteristics
- Given that the seasonal window of peak EWM biomass is both short and typically cloudy in the Great Lakes, how can UAS play a practical role in generating these maps?
  - Rapid deployment, high resolution, multispectral data (Methods)

Methods: UAS natural color

UAS-based aerial natural color (RGB) imagery

Wide, tiltable platform on Bergen can carry a DSLR & multispectral camera payloads

Boat-deployable platforms: the ~1 m diameter Bergen Hexacopter (left) and 350 mm DJI Phantom
15-20 minutes flight time, ~300m to 1 km radius, 15-30 ha

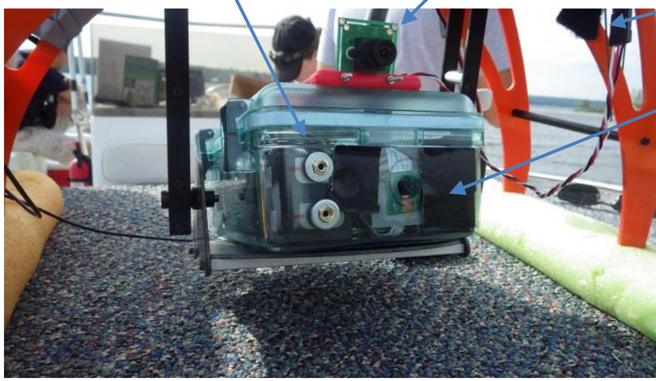
DJI Phantom has an integrated RGB camera

Methods: spectral profiles

Spectrometer optics *Heads-up display camera*

GPS receiver

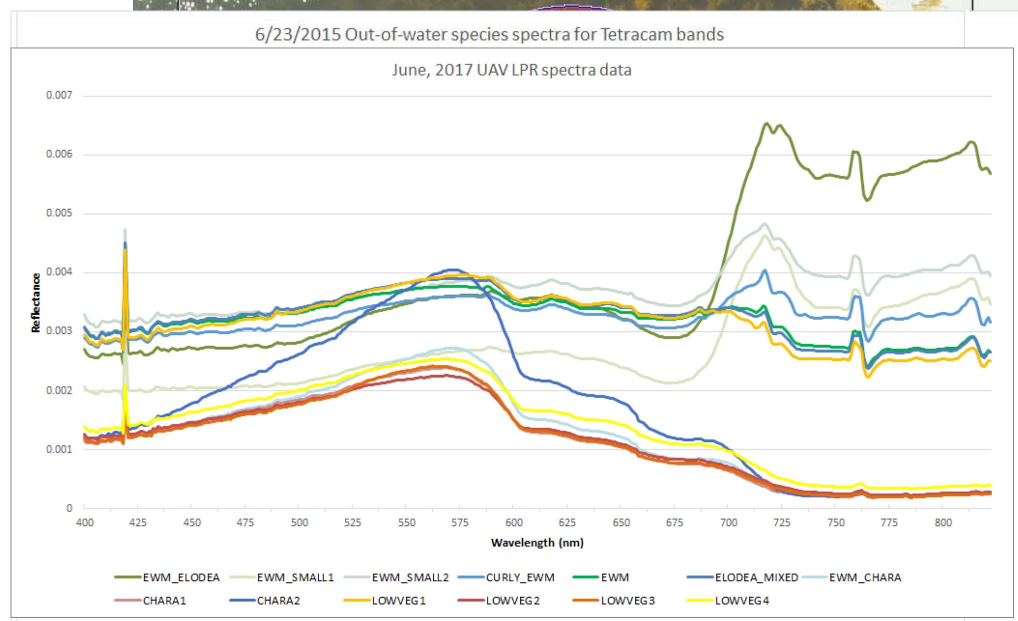
Camera for simultaneous FOV reference photos

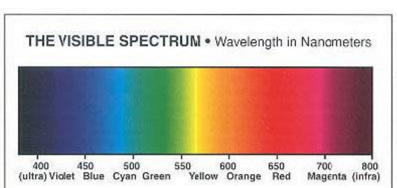


Verified results with field spectroradiometers
- Out-of-water
- boatside
- from UAV

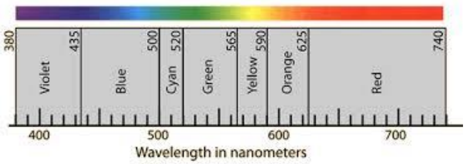
Used both a traditional ASD backpack Fieldspec3 spectrometer and portable OceanOptics STS *lightweight portable radiometer* (LPR) developed by MTRI

- OceanOptics was mounted on the Bergen hexacopter
- Visible + NIR range
- 325-1075 nm
- Obtain spectral profiles of SAV

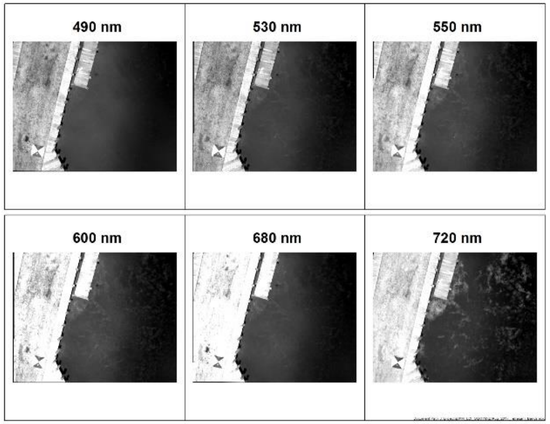




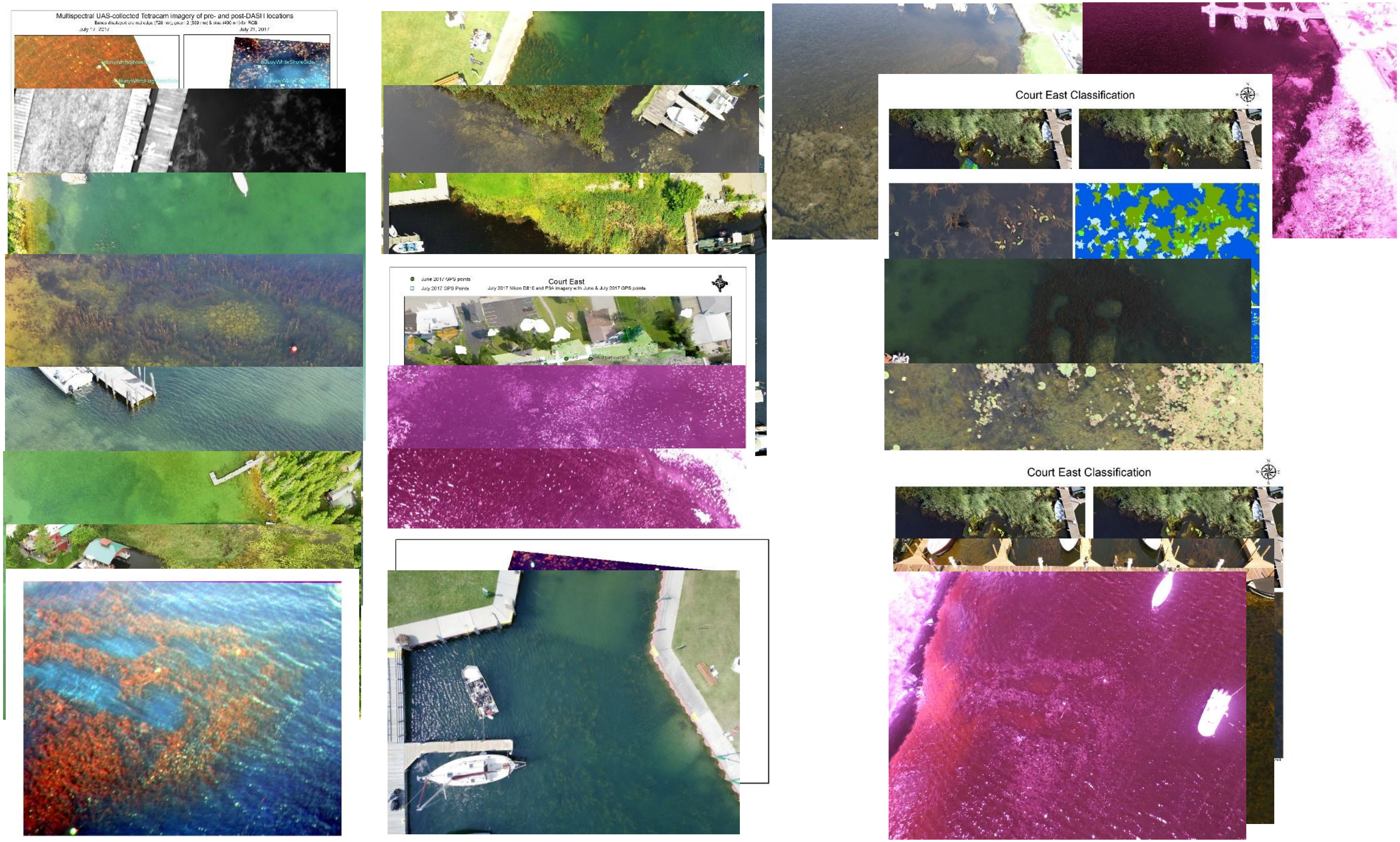
Methods: multispectral camera



- Tetracam Micro-MCA, 6 imaging sensors, 1.3mp CMOS
- Default bands, but can request custom filters
  - Standard are 490, 550, 680, 720, 800, 900 nm
  - Operated in Les Cheneaux Islands in 2016 using 490 (blue), 530 (green 1), 550 (green 2), 600 (yellow/orange), 680 (red) and 720 (red edge) nm filters more suited to aquatic mapping
- GPS input capability & incident light sensor for radiance calibration
- Also tested MTRI-built 4-band (RGB + near infrared) "VISNIR" two-camera system



Example UAS-collected imagery



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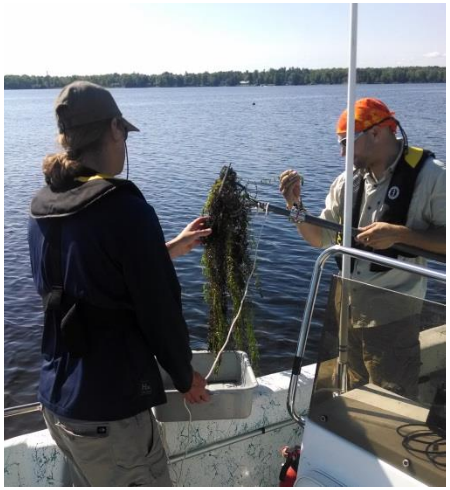
Methods

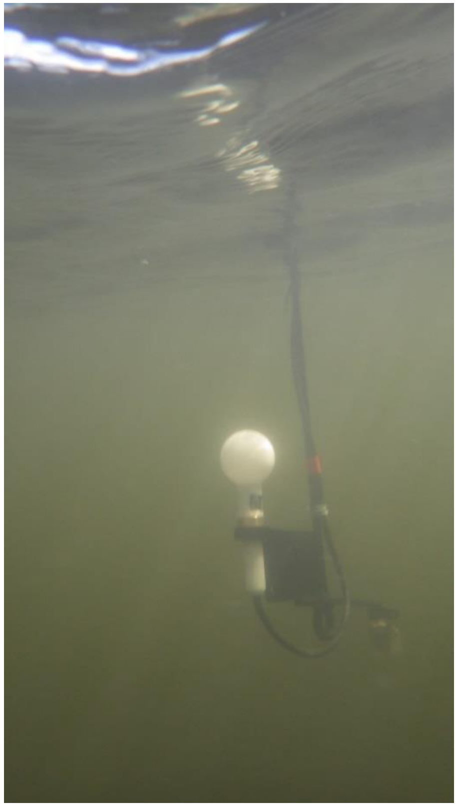
Field vegetation/water data collection

Rake toss sampling



Twist rake sampling

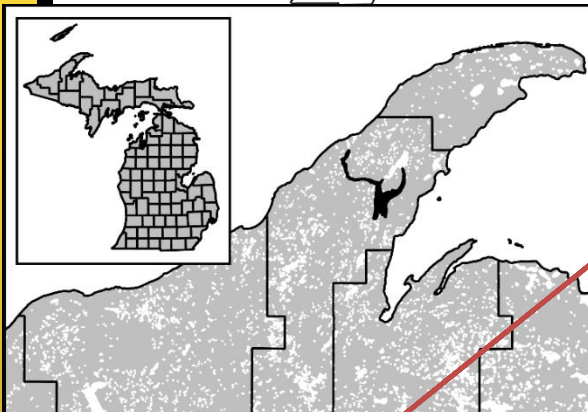
Sonde

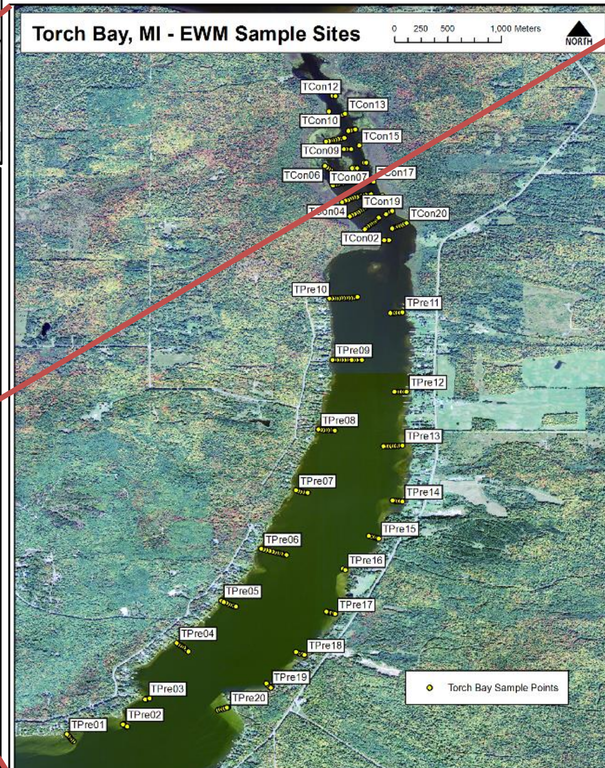


LI-COR light meter

Characterize the water (chl, sm, doc), vegetation (species/frequency/biomass) & light levels (a/b, SDT)

Case Study 1: Keweenaw Waterway, Lake Superior EWM Program

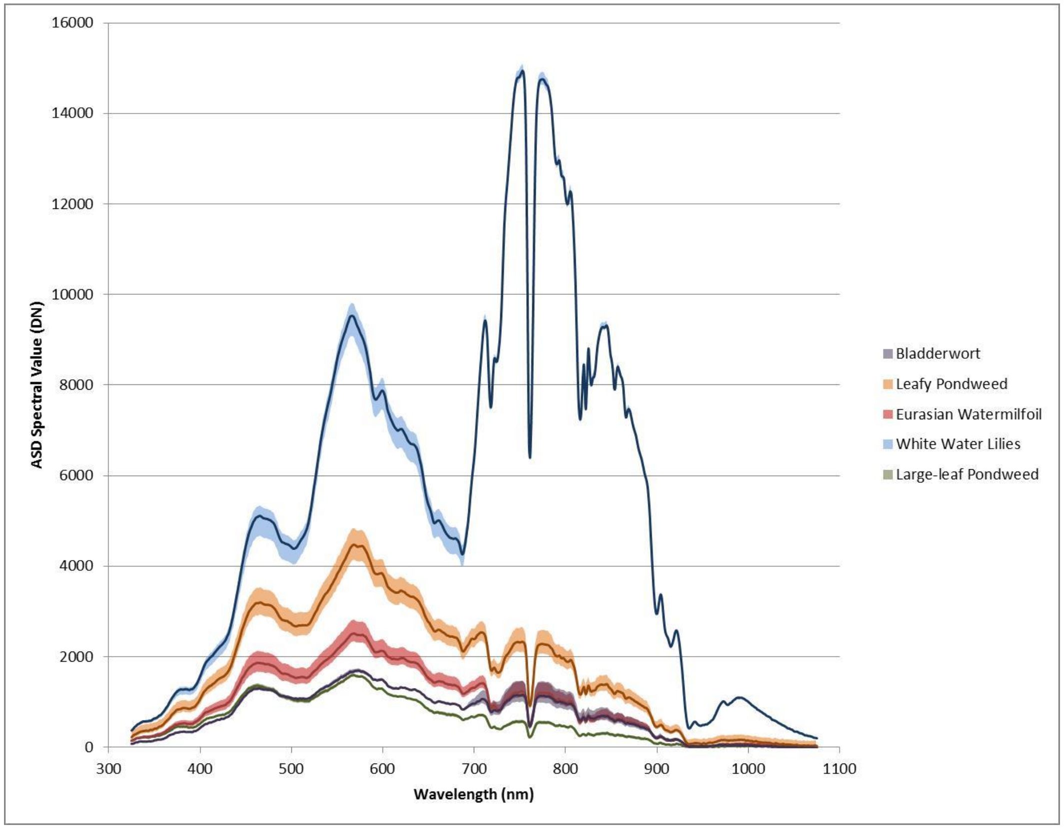




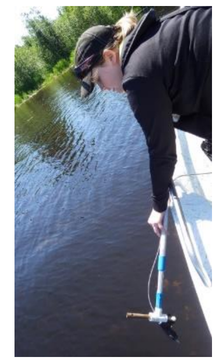
GLRI-EPA : Arresting the Spread of Eurasian Watermilfoil in Lake Superior (2014-2016)
MDNR-MISGP: Innovative and multifaceted control of invasive Eurasian and hybrid watermilfoil using integrative pest management principles (2015-2017)
C.Huckins, PI (Michigan Tech)

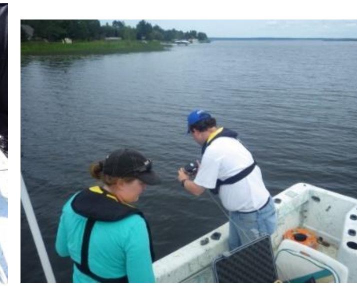
Case Study 1: Keweenaw Waterway

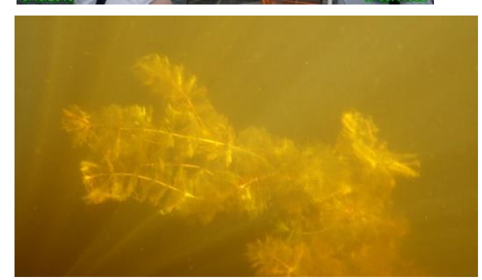
SAV In-Water Spectral Signatures (Keweenaw Waterway heavily tannin-stained water conditions)



- *For SAV, the water column can alter and attenuate the signal reflected from the vegetation.*

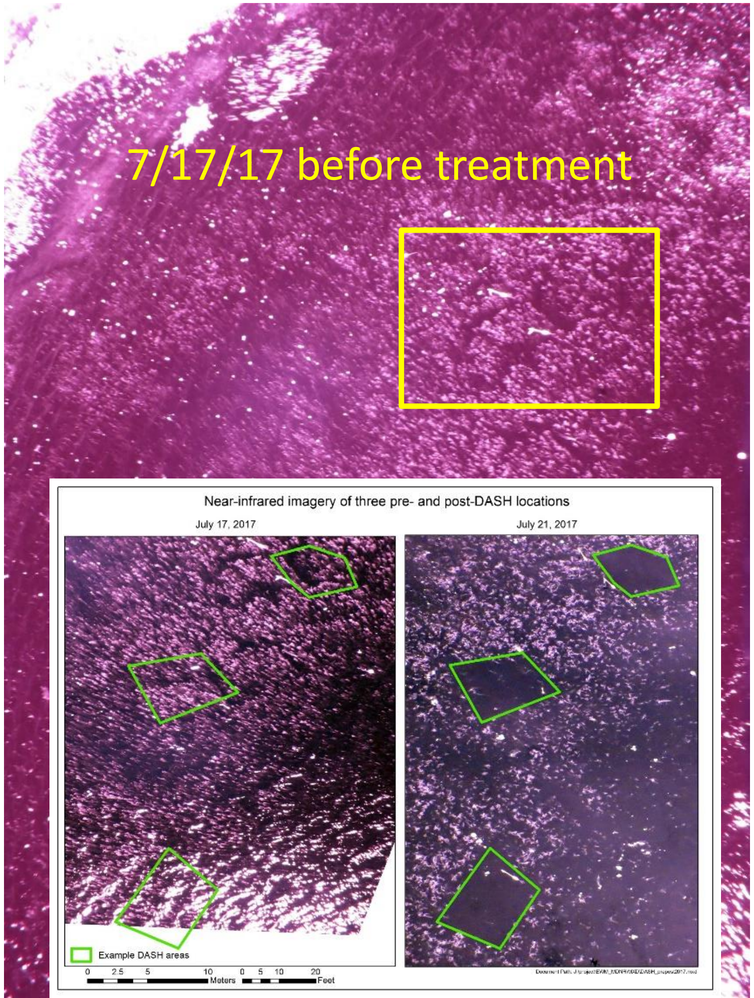


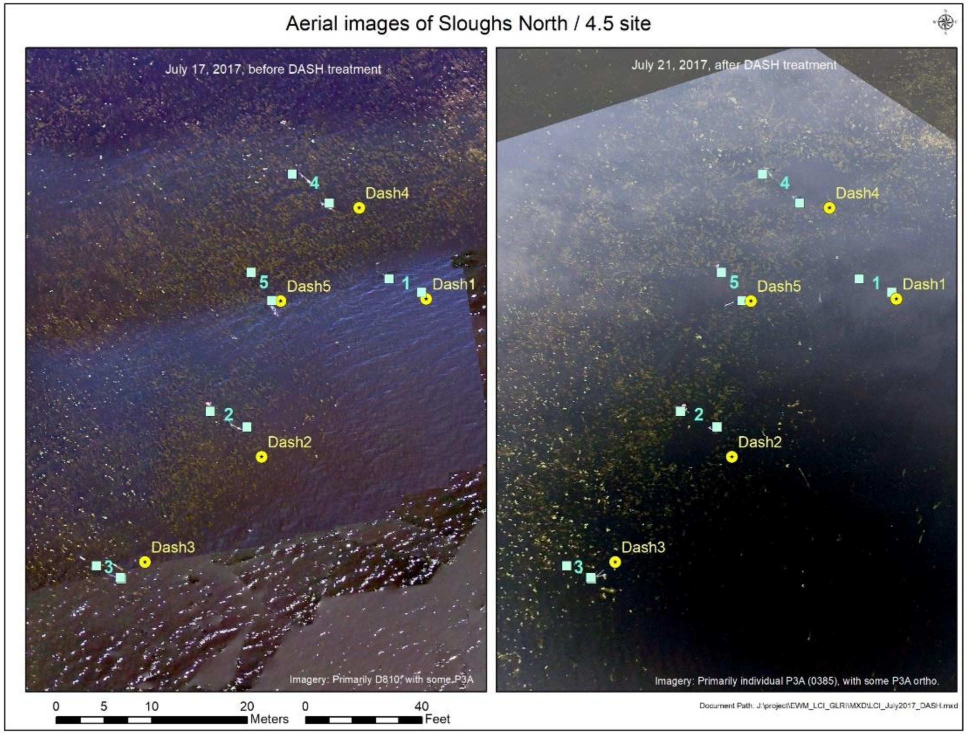




Case Study 1: Tracking DASH treatments

- Monitoring Diver Assisted Suction Harvesting (DASH) treatment with before/after multispectral imagery





Areas of DASH treatment are clearly visible in NIR (& RGB) images from MTRI VISNIR system

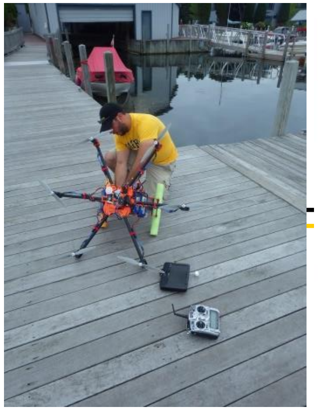
- *Areas can be tracked & quantified*
- *3 areas at left total 58.7 m^2 (672 ft^2)*

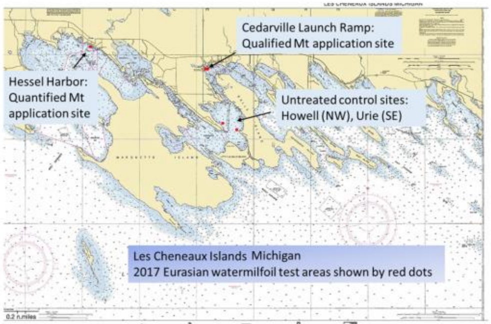
Case Study 2:

Les Cheneaux Islands, Lake Huron Eurasian Watermilfoil Control

- Focused on testing & demonstrating of native fungus (*Mycoleptodiscus terrestris or “Mt”*), alternative to herbicides
  - Previous native weevil work
- Map EWM and other aquatic veg on ~800 acres
  - Also track effectiveness of Mt with pre- & post-control mapping enhanced through UAVs
- Working closely with Les Cheneaux Watershed Council – Bob Smith, Mark Clymer
- Field work starting in 2016, project completed 9/30/2018
  - US EPA GLRI funding

Great Lakes RESTORATION

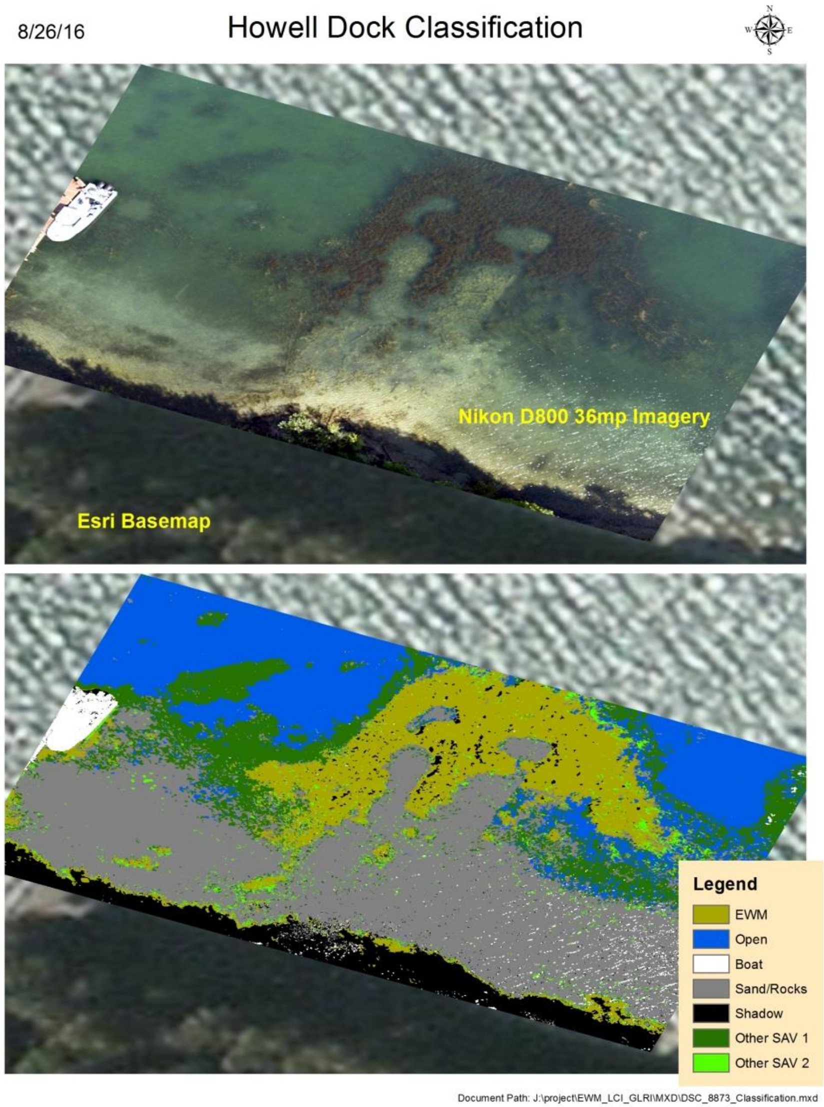




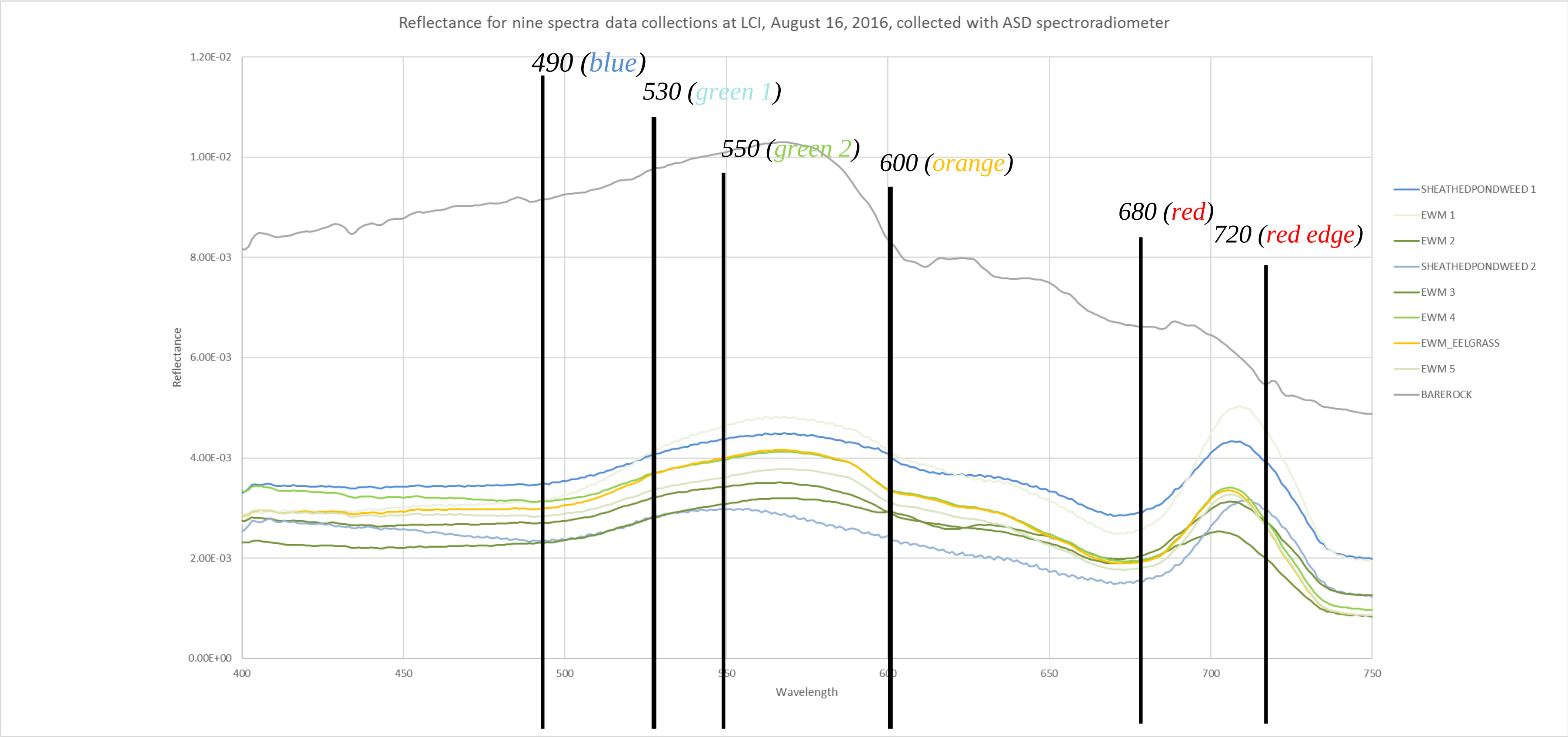
Case Study 2: Les Cheneaux

Hexacopter-mounted Nikon DSLR

- Hexacopter-collected aerial image of EWM in Les Cheneaux, segmented using eCognition object-based image analysis software
- Provides sharp, high definition but less spectral information with which to differentiate similar vegetation types



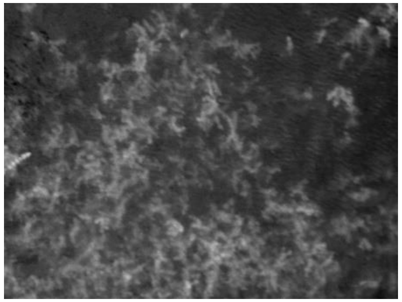
Case Study 2: Les Cheneaux

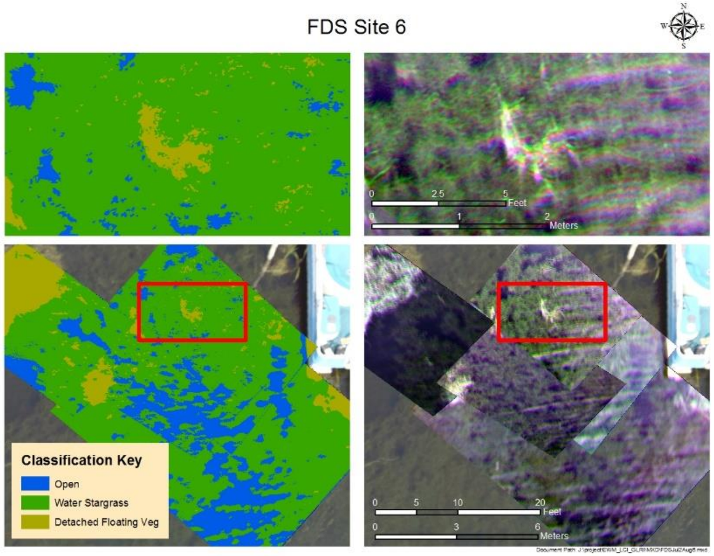


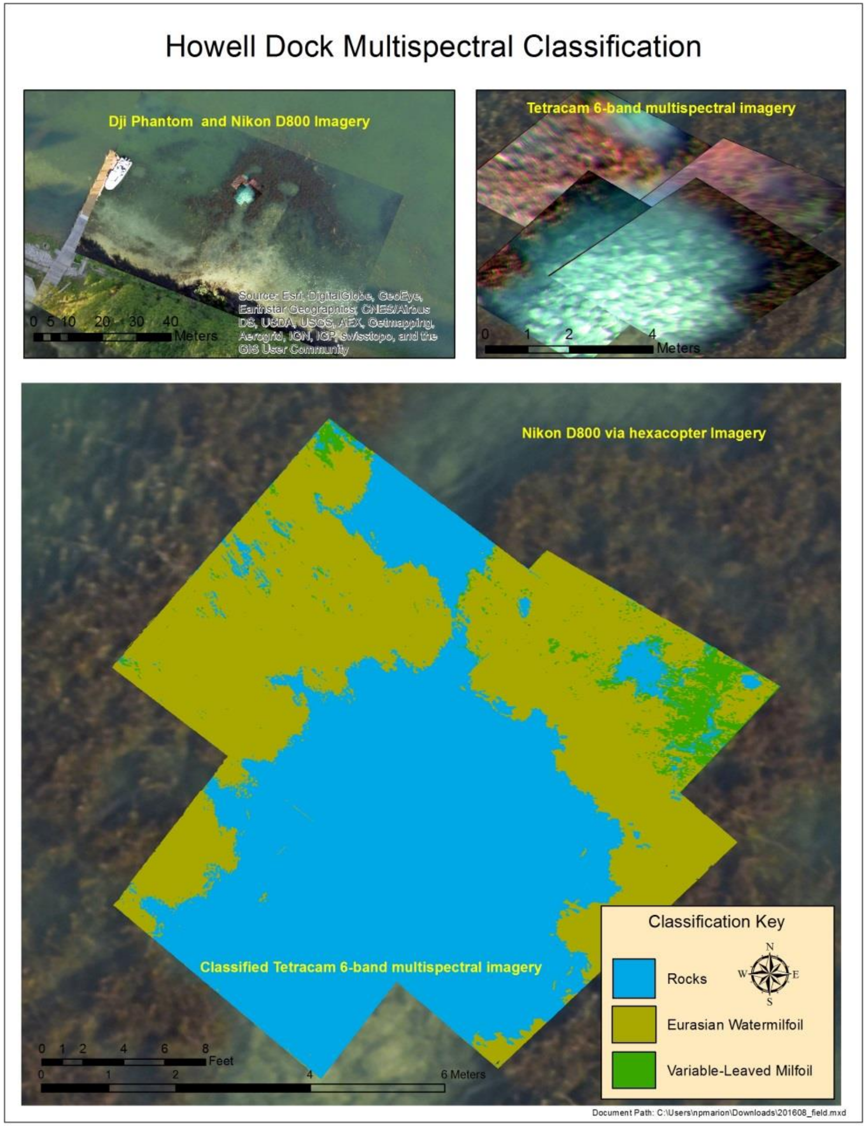
- The spectral signatures of common aquatic macrophytes show significant overlap, but also marked differences in shape that can be exploited with carefully selected bands & band ratios
- Key bands can be collected using a Tetracam tunable multispectral camera

Case Study 2: Les Cheneaux

Given favorable conditions, the 6 narrow Tetracam spectral bands can enable differentiation between EWM and the desirable native milfoil present at Les Cheneaux







Case Study 2: Les Cheneaux

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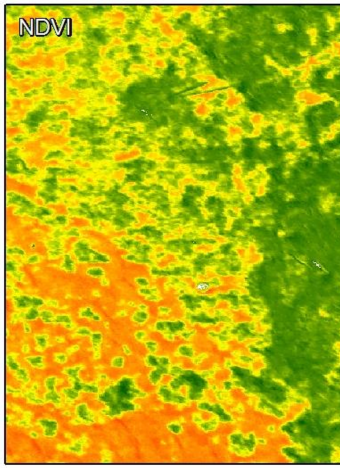
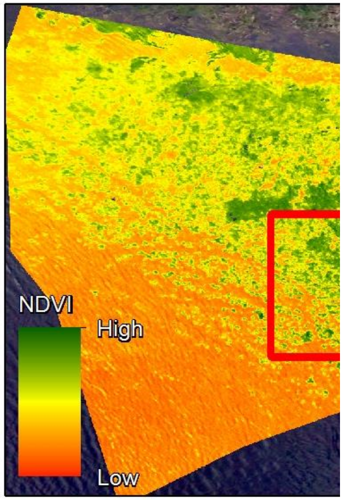
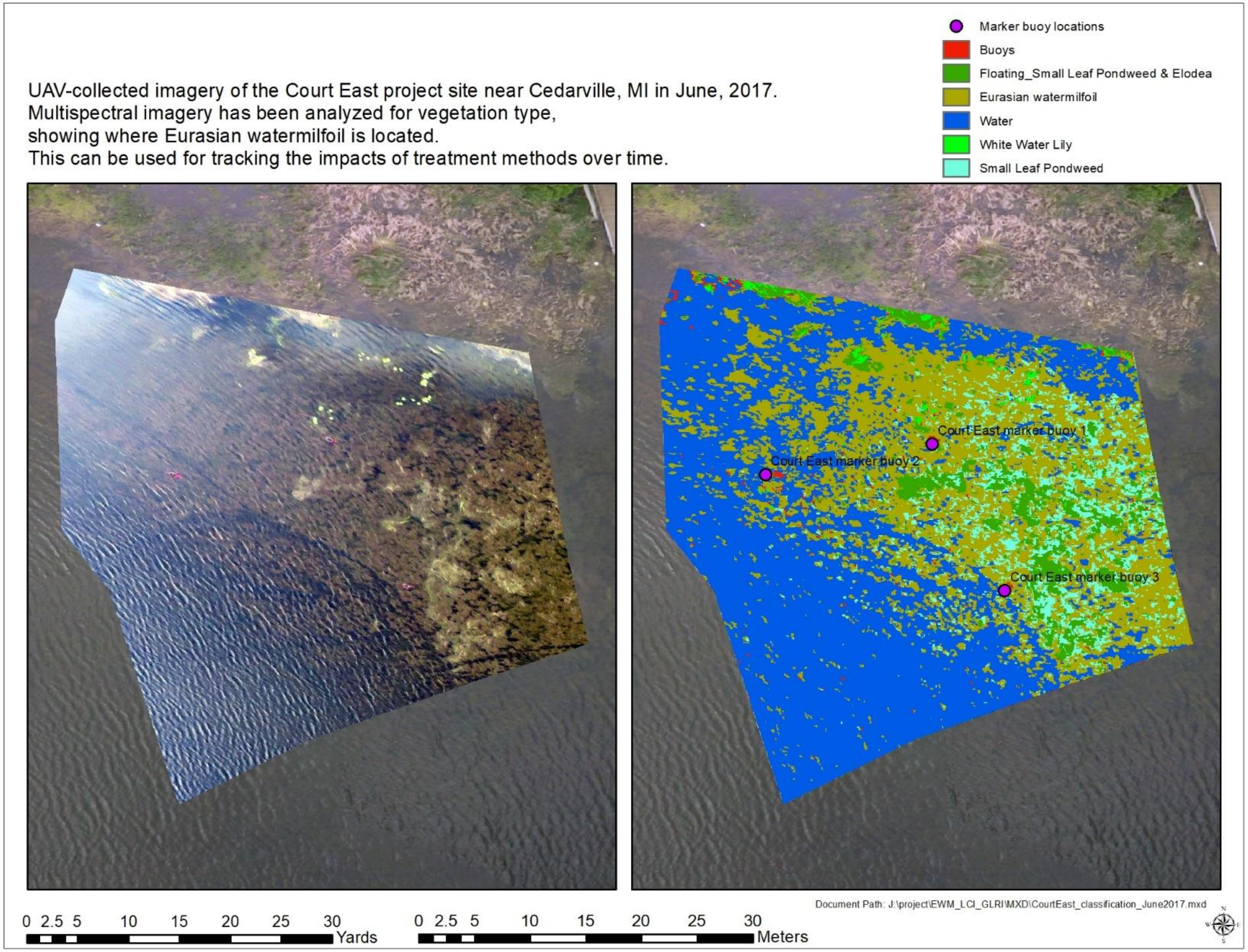
Multispectral imagery mapping results – EWM is distinguishable

6/20/17



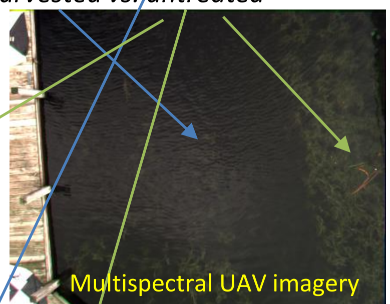


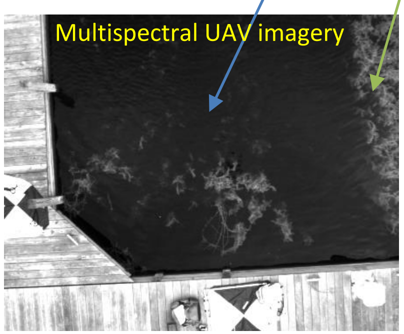


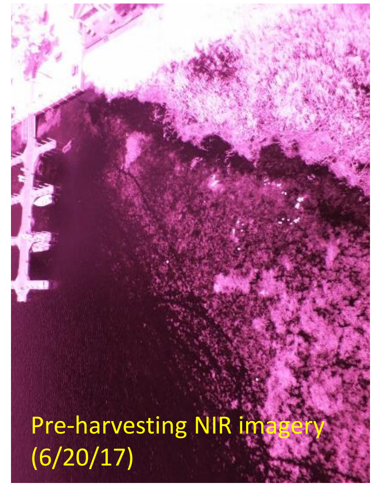
Can track & quantify where mechanical harvesting has taken place

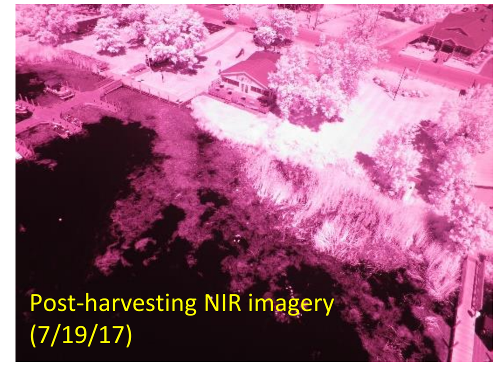
Boat slip area with mech. harvesting

Harvested vs. untreated



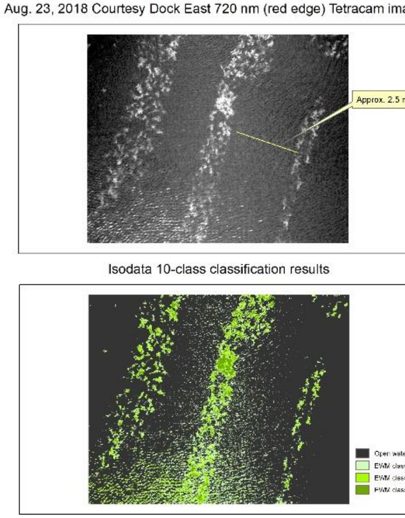






Harvest

Aug. 23, 2018 Courtesy Dock East 720 nm (red edge) Tetracam image

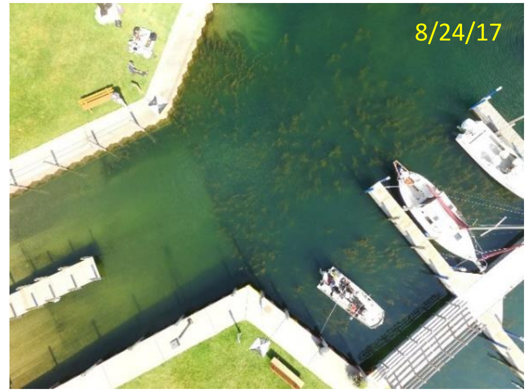


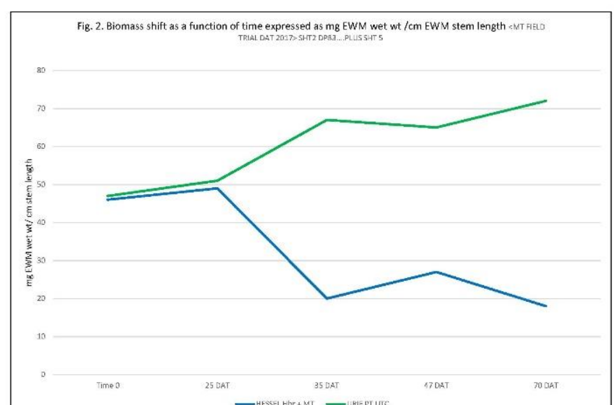
Open water	1091475	83.3%
EWM 1	140719	10.7%
EWM 2	55528	4.2%
EWM 3	22998	1.8%
Sum	1310720	
EWM total	219245	16.7%

16.7% of treated area has remained as EWM (about 12.5 m2 of 75 m2… 130 of 800 ft2)

Evaluating main Mt fungus treatment site (Hessel Marina)

- Mt fungus applied late July, 2018 (7/28/17)
- Visited application areas in early season, midseason, and almost 4 weeks (26 days) after application
- Partners at Les Cheneaux Watershed Council visited up to 70 days later
  - Up to 70% biomass decline 70 days later; not seen at untreated site
- Revisited one year later – less dense (quantifying)





Biomass of untreated control increased ∫ time compared with Mt-treated EWM that began to decrease in biomass after the 25 day measurement.

It appears that the Mt-infection took over three weeks to be reflected in decreased biomass expressed as mg EWM wet wt per cm stem length

Current analysis being completed for dissertation papers

- Band ratios & indices
  - Red Edge (720 nm) / Blue (490 nm)
  - NDVI (normalized difference vegetation index) – good for detecting green biomass, limited penetration of NIR
  - Water-adjusted vegetation indices (Villa et al. 2014)
    - NDAVI – Normalized Difference Aquatic Vegetation Index
    - WAVI – Water Adjusted Vegetation Index
- Kolmogorov-Smirnov (K-S) test – are spectral curves (distributions) different?
  - Looking at all 651 bands, 66 bands average to 10-nm wide, 8 wetlands bands (Becker et al. 2005), 6 bands corresponding to Tetracam
    - More bands provide differentiation
- Mixed models – what factors are having the greatest impact?
  - 490, 530, 550, 680, 720, RE/BLUE, NDVI, NDAVI, WAVI for each of 62 vegetation surveys
  - Tested for:
    - Dominant vegetation group effect
    - Month effect
    - Dominant vegetation & month interaction
  - NDVI significant to differentiating

Ratio evaluations

Species	RE:R (720:680)	RE:O (720:600)	RE:G2 (720:550)	RE:G1 (RE:G1)	RE:B (RE:B)	NDVI
CURLYLEAF	13.105	8.401	10.17	11.749	21.885	0.858206719
FERNLEAF	3.637	2.975	3.261	3.735	5.183	0.56866693
EWM1	4.087	2.969	3.55	3.876	5.246	0.606817189
EWM2	5.295	3.585	4.556	5.017	7.002	0.682294651
CLASPING	6.118	3.845	3.035	3.494	7.088	0.719032036
CHARA	6.898	3.844	3.14	3.944	8.974	0.746756085
NORTHERN	2.837	2.131	2.118	2.266	2.998	0.478780018
WHITESTEM	6.477	3.895	3.645	4.301	8.277	0.732530448
VARIABLE	5.238	2.91	2.889	3.28	6.126	0.679380413
TARP	0.998	0.992	0.992	0.989	0.985	-0.000908099
STDDEV (notarp)	2.997	1.808	2.390	2.772	5.473	0.11096

RE/BLUE has greatest variation

K-S test of June 2017 out-of-water spectral data

averaged to 66 10-nm wide bands

Tested profile		Species profile	p-value		Tested profile		Species profile	p-value	
EWM1	vs	CURLYLEAF	0.0000209	***	EWM2	vs	CURLYLEAF	0.0000209	***
		FERNLEAF	0.00746	**			FERNLEAF	0.00211	**
		EWM2	0.03858	*			EWM1	0.03858	*
		CLASPING	0.0625				CLASPING	0.0133	*
		CHARA	0.0001122	***			CHARA	0.0133	*
		NORTHERN	0.00000336	***			NORTHERN	0.00000336	***
		WHITESTEM	0.0000209	***			WHITESTEM	0.0000209	***
		VARIABLE	0.004037	**			VARIABLE	0.00107	**
		TARP	<0.0000001	***			TARP	<0.0000001	***

*** = significant at p<0.001; ** = significant at p<0.01; * = significant at p<0.05

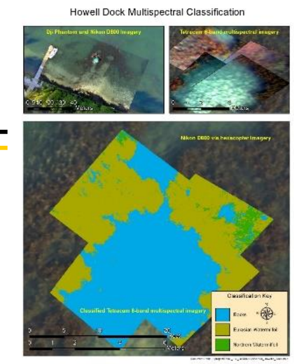
66 bands – can differentiate species

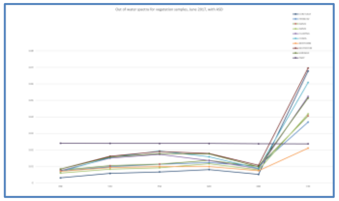
Mixed model	**NDVI**	
Effect	*F-value*	*Pr>F*
DOMVEG_GRP	**3.16**	**0.0402**
MONTH	1.54	0.2437
DOMVEG_GRP*MONTH	2	0.1398

NDVI different among veg groupings at p=0.05

Conclusions

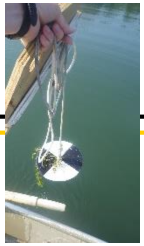
- IWM/EWM can be sufficiently spectrally distinct from other common aquatic macrophytes in the nearshore Great Lakes to distinguish it in hyperspectral & multispectral imagery
- The strong effects of bathymetry and water color mean that spectral methods work best for sites where these characteristics can be well understood
- UAV platforms enable very-high-res imagery collection that complements spectral profiling for use in vegetation classification mapping
  - Tunable multi-spectral imaging creates ability to differentiate species better; NDVI important
  - Useful for tracking treatment areas (biomass changes – presence/absence)
- This approach can be applicable for monitoring other native and non-native macrophytes & their treatments across a variety of shallow aquatic habitats
  - Great Lakes & elsewhere

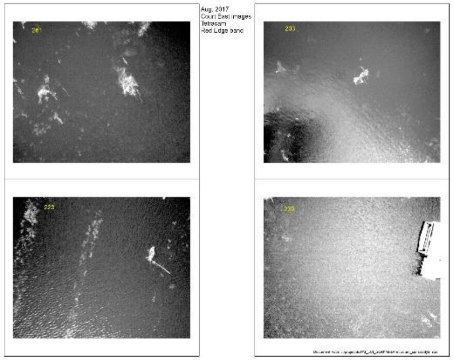




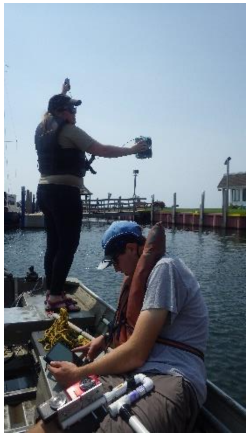
Contact







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