City of Saugatuck EST. 1868

CITY COUNCIL AGENDA
JUNE 8, 2020 – 7:00 P.M.

NOTICE:

This public meeting will be held using Zoom video/audio conference technology due to the COVID-19 restrictions currently in place.

Join online by visiting: **https://us02web.zoom.us/j/2698572603**

Join by phone by dialing: **(312) 626-6799 -or- (646) 518-9805**

Then enter "Meeting ID": **2698572603**

Please send questions or comments regarding meeting agenda items prior to meeting to: kirk@saugatuckcity.com

1. CALL TO ORDER
2. ROLL CALL
3. APPROVAL OF MINUTES
   A. Special City Council Meeting of May 28, 2020 - *(ROLL CALL)*
4. MAYOR'S COMMENTS
5. CITY MANAGER'S COMMENTS
6. AGENDA CHANGES (ADDITIONS/DELETIONS)
7. GUEST SPEAKERS:
   A. Colin Brooks –Michigan Technological University (Eurasian Water Milfoil)
   B. Lt. Brett Ensfield – Allegan Co. Sheriff Department
8. PUBLIC COMMENT *(Limit 3 minutes) Select "unmute" mic in the Zoom interface and speak your name to be recognized or press *6 if you are calling in by phone to unmute your phone to speak.*
9. REQUESTS FOR PAYMENT
   A. Approval of Accounts Payable *(ROLL CALL)*
10. INTRODUCTION OF ORDINANCES:
    A. Ordinance Amendment – 154.041, Chapter 154, Title XV, of the Code of the City of Saugatuck, entitled "Land Usage; Zoning Code section 154.005, 154.024, 154.039, 154.040, and 154.041 *(ROLL CALL)*
11. PUBLIC HEARINGS: **None**
12. UNFINISHED BUSINESS: **None**
13. NEW BUSINESS
    A. City Manager Interim City Clerk Appointment *(ROLL CALL)*
14. CONSENT AGENDA: **None**
15. PUBLIC COMMENTS *(Limit 3 minutes) Select "unmute" mic in the Zoom interface and speak your name to be recognized or press *6 if you are calling in by phone to unmute your phone to speak.*
16. COMMUNICATIONS:
    A. Kalamazoo Harbor Invasive Species (Eurasian Water Milfoil)
    B. (Pending) Attorney Communication re: Dunegrass request
17. BOARDS, COMMISSIONS & COMMITTEE REPORTS
18. COUNCIL COMMENTS
19. ADJOURN *(ROLL CALL)*

Requests for accommodations or interpretive services must be made 48 hours prior to this meeting. Please contact Saugatuck City Clerk at 269-857-2603 or kirk@saugatuckcity.com for further information.

PROPOSED Minutes
Saugatuck City Council Special Meeting
Saugatuck, Michigan, May 28, 2020

The City Council met in special session at 4:00 p.m. via Zoom video/audio conference technology due to the COVID-19 restrictions currently in place.

1. **Call to Order** by Mayor Trester at 4:00 p.m.

2. Attendance:
Present: Bekken, Johnson, Leo, Lewis, Peterson, Verplank, & Trester
Absent: None
Others Present: City Manager Harrier, DPW Superintendent Herbert, Zoning Administrator Osman & City Clerk Nagel

3.. Approval of Minutes:
A. Regular City Council Meeting of May 26, 2020: A motion was made by Johnson, 2nd by Leo, to approve the minutes as corrected to incorporate the following language under agenda item 14(F). Upon roll call the motion carried unanimously.

At 1:34 Johnson recommends that a motion be made or that the proposal be tabled until the next meeting.
At 1:35:10 Lewis moves to "call a special meeting of the City Council for this Thursday to move forward on discussion and decision regarding this proposal."
At 1:36:22 Peterson indicates that "I did second the motion."

4. Mayor's Comments: None

5. City Manager's Comments: None

6. Agenda Changes: None

7. Guest Speakers: None

8. Public Comment None

9. Request for Payment: None

10. Introduction of Ordinances: None

11. Public Hearings: None

12. Unfinished Business:

13. New Business:
A. Downtown Pop-Up Patio/Dining in the Right-of-Way Permit or Lease: Motion to allow staff to administratively issue permits for the pop up patios with or without alcoholic beverages as described/amended in the attached documents effective immediately through October 30, 2020, and allow the staff to administratively approve the tentative sidewalk sale for June 19, 2020, assuming the stay home order is lifted. A motion was made by Johnson, 2nd by Verplank, to amend motion to strike the sentence that starts with "*and allow the staff administratively approve the tentative sidewalk sale for June 19, 2020 assuming the stay at home order is lifted."* Upon roll call the motion carried unanimously.

A motion was made by Johnson, 2nd by Verplank, to approve motion as amended. Upon roll call the motion carried unanimously.

14. Consent Agenda: None

15. Public Comment: Elizabeth Estes thanked Council for approving agenda item 13(A) and offered help to come up with possible solutions for business on Culver Street.

16. Communications: None

17. Boards, Commissions & Committee Reports: None

18. Council Comments: Council Member Johnson thanked Council Members for following Roberts Rules of Order.

Council Members Leo, Bekken & Trester thanked the Pop-up Patio/Dining in Right of Way Committee.

Council Member Lewis thanked individuals attending Zoom meeting.

Council Member Verplank announced Pop-up Patio/Dining in Right of Way Committee has been working as fast as possible to come up with solutions for downtown businesses.

19. Adjournment: A motion was made by Peterson, 2nd by Verplank, to adjourn at 4:53 p.m. Upon roll call the motion carried unanimously.

Respectfully Submitted,

Monica Nagel, CMC
City Clerk

Vendor Name	Description		Amount
1. AT&T MOBILITY			
	CELL PHONES		94.60
2. BELL EQUIPMENT CO			
	STREET SWEEPER		649.00
3. CONSUMERS ENERGY			
	STREET LIGHTS		2,059.27
4. ETNA SUPPLY			
	FLOODING		1,280.00
5. FIRST BANK CARD			
	WEBSITE & MEETINGS		329.54
	PARKS		125.88
	CONCESSION OVAL FLOODING		1,345.67
		TOTAL	1,801.09
6. FLEIS & VANDENBRINK ENGINEERING INC			
	PARK STREET		476.50
7. FRONTIER			
	OVAL		283.78
	OVAL		61.21
	DPW GARAGE		170.75
		TOTAL	515.74
8. GORDON FOOD SERVICE			
	CONCESSION		2,065.45
9. GRAND RAPIDS POPCORN			
	CONCESSION		404.15
10. GROUNDS MANAGEMENT SOLUTIONS			
	PARKS MAINTENANCE		531.00
11. HOLLAND MEDI-CENTER			
	DOT PHYSICAL		46.00
12. KALAMAZOO LAKE SEWER & WATER			
	WATER & SEWER		1,304.61
13. KATIE STARRS			
	FEE RETURN COGHLIN		500.00
14. MERS			
	RETIREMENT		4,500.00
15. MICHIGAN GAS UTILITIES			
	BUTLER STREET BATHROOM		75.89
	DPW GARAGE		85.34
	CITY HALL		57.60
		TOTAL	218.83
16. MINER SUPPLY CO			
	SUPPLIES		445.05
	SUPPLIES		585.00
		TOTAL	1,030.05
17. OVERISEL LUMBER COMPANY			
	SUPPLIES		298.45
18. PLAINWELL REDI MIX			
	RETAINING BLOCKS		1,408.00
19. PLUMMER'S ENVIRONMENTAL SERVICES IN			
	STORM SEWER CLEANING		2,760.00
20. PURITY CYLINDER GASES INC			
	CONCESSION		14.88
21. REPUBLIC SERVICES			
	TRASH		414.95
	TRASH		180.00
		TOTAL	594.95

Vendor Name	Description	Amount
22. SHELL		
	GASOLINE & DIESEL	620.27
23. SHORELINE TECHNOLOGY SOLUTIONS		
	COMPUTER SERVICES	564.25
24. STANDARD INSURANCE COMPANY		
	INSURANCE	308.02
25. VALLEY CITY LINEN INC		
	SHOP TOWELS	290.65
26. WESTENBROEK MOWER INC		
	TORO REPAIRS	573.44
27. XEROX FINANCIAL SERVICES		
	COPIER LEASE	451.68
TOTAL - ALL VENDORS		25,360.88

FUND TOTALS:

Fund 101 - GENERAL FUND	22,112.19
Fund 202 - MAJOR STREETS	24.82
Fund 203 - LOCAL STREETS	501.32
Fund 661 - MOTOR POOL FUND	2,669.75
Fund 715 - ROSE GARDEN	52.80

06/04/2020	CHECK REGISTER FOR CITY OF SAUGATUCK			
CHECK DATE FROM 05/01/2020 - 05/31/2020				
Check Date	Check	Vendor Name	Description	Amount
Bank GEN GENERAL POOLED CASH				
05/01/2020	DD4446(A)	BULTMAN, LINDA	PAYROLL	1,113.73
05/01/2020	DD4447(A)	HARRIER, KIRK	PAYROLL	2,158.50
05/01/2020	DD4448(A)	HERBERT, SCOTT	PAYROLL	1,586.64
05/01/2020	DD4449(A)	KAZDA, NATHAN	PAYROLL	1,136.47
05/01/2020	DD4450(A)	KERRIDGE, ADAM	PAYROLL	1,122.90
05/01/2020	DD4451(A)	NAGEL, MONICA	PAYROLL	1,568.85
05/01/2020	DD4452(A)	OSMAN, CINDY	PAYROLL	1,405.23
05/01/2020	DD4453(A)	STANISLAWSKI, PETER	PAYROLL	1,400.43
05/01/2020	DD4454(A)	WENDT, MICHAEL	PAYROLL	1,201.31
05/01/2020	EFT1282(E)	457-VALIC	PAYROLL	3,672.48
05/01/2020	EFT1283(E)	STATE OF MICHIGAN	PAYROLL	185.06
05/01/2020	EFT1284(E)	MERS HYBRID	PAYROLL	1,178.82
05/01/2020	EFT1285(E)	FEDERAL TAX DEPOSIT	PAYROLL	4,814.09
05/11/2020	16435	ALLEGAN COUNTY HEALTH DEPT	CONCESSION LICENSE	355.00
05/11/2020	16436	EDGEWATER RESOURCES	HIGH WATER RIVERFRONT	824.16
05/11/2020	16437	GIL- ROY'S HARDWARE	PARKS	178.18
05/11/2020	16438	KALAMAZOO LAKE SEWER & WATER	DELIQUENT WATER TAX	111.62
05/11/2020	16439	SHERWIN WILLIAMS	GLASS BEADS STREET	883.12
05/11/2020	16441	CAPITAL ONE	MAINTENANCE	8.45
05/11/2020	2883(E)	CONSUMERS ENERGY	ELECTRIC	2,835.81
05/11/2020	2884(E)	FIRST BANK CARD	TRAINING	178.89
05/11/2020	2885(E)	KALAMAZOO LAKE SEWER & WATER	WATER & SEWER	921.27
05/11/2020	2886(E)	PRIORITY HEALTH	HEALTH INSURANCE	6,959.13
05/11/2020	2887(E)	SHELL	GASOLINE & DIESEL	625.49
05/11/2020	2888(E)	VALLEY CITY LINEN INC	SHOP TOWELS	38.70
05/11/2020	2889(E)	XEROX FINANCIAL SERVICES	COPIER LEASE	451.68
05/11/2020	2890(A)	BBC DISTRIBUTING LLC	SAFETY SUPPLIES	365.00
05/11/2020	2891(A)	BS&A SOFTWARE	SOFTWARE UPDATES	995.00
05/11/2020	2892(A)	FLEIS & VANDENBRINK ENGINEERING IN	PARK STREET	1,339.53
05/11/2020	2893(A)	GLASS IMAGES INC	COVID CITY HALL WINDOWS	410.00
05/11/2020	2894(A)	INTERURBAN TRANSIT AUTHORITY	PROPERTY TAXES	3,399.65
05/11/2020	2895(A)	MC NALLY ELEVATOR COMPANY INC	ELEVATOR CITY HALL	420.50
05/11/2020	2896(A)	MICHIGAN OFFICE SOLUTIONS	COPIER USE	106.37
05/11/2020	2897(A)	MICHIGAN WOOD FIBERS	PARK MULCH	997.50
05/11/2020	2898(A)	RHOMAR INDUSTRIES INC	EQUIPMENT CLEANER	735.41
05/11/2020	2899(A)	SAUGATUCK FIRE	PROPERTY TAXES	15,396.89
05/11/2020	2900(A)	SEPTIC TANK SYSTEMS CO INC	HAND WASHING STATIONS	220.00
05/11/2020	2901(A)	SHORELINE TECHNOLOGY SOLUTIONS	COMPUTER SERVICES	1,563.25
05/11/2020	2902(A)	STREAMLINE DESIGN.COM LLC	COVID GUARDS	133.00
05/11/2020	2903(A)	TRUCK & TRAILER SPECIALTIES	TRUCK REPAIR	912.36
05/11/2020	16440	WESTENBROEK MOWER INC	MOWER PARTS & REPAIRS	404.19

06/04/2020		CHECK REGISTER FOR CITY OF SAUGATUCK		
		CHECK DATE FROM 05/01/2020 - 05/31/2020		
Check Date	Check	Vendor Name	Description	Amount
05/15/2020	DD4455(A)	BULTMAN, LINDA	PAYROLL	1,309.00
05/15/2020	DD4456(A)	GOODRICH, RICHARD	PAYROLL	339.52
05/15/2020	DD4457(A)	HARRIER, KIRK	PAYROLL	2,158.51
05/15/2020	DD4458(A)	HERBERT, SCOTT	PAYROLL	1,651.63
05/15/2020	DD4459(A)	KAZDA, NATHAN	PAYROLL	1,176.49
05/15/2020	DD4460(A)	KERRIDGE, ADAM	PAYROLL	1,518.90
05/15/2020	DD4461(A)	NAGEL, MONICA	PAYROLL	1,568.84
05/15/2020	DD4462(A)	OSMAN, CINDY	PAYROLL	1,405.21
05/15/2020	DD4463(A)	STANISLAWSKI, PETER	PAYROLL	1,400.42
05/15/2020	DD4464(A)	WENDT, MICHAEL	PAYROLL	1,241.31
05/15/2020	EFT1286(E)	457-VALIC	PAYROLL	3,688.88
05/15/2020	EFT1287(E)	STATE OF MICHIGAN	PAYROLL	185.06
05/15/2020	EFT1288(E)	MERS HYBRID	PAYROLL	1,183.68
05/15/2020	EFT1289(E)	FEDERAL TAX DEPOSIT	PAYROLL	5,040.57
05/20/2020	16442	PETTY CASH	OVAL BEACH START UP	3,000.00
05/26/2020	16443	ALLEGAN COUNTY NEWS	PRINTING	161.00
05/26/2020	16450	PETTY CASH	ADDITIONAL START UP	2,000.00
05/26/2020	2907(A)	ACCURATE STRIPING	STREET PAINTING	6,957.85
05/26/2020	2908(A)	ALLEGAN COUNTY SHERIFF	SHERIFF CONTRACT	25,725.72
05/26/2020	2909(A)	BBC DISTRIBUTING LLC	SAFETY SUPPLIES	180.00
05/26/2020	2910(A)	BLOOM SLUGGETT PC	LEGAL FEES	3,400.00
05/26/2020	2911(A)	DIANNA MC GREW	ASSESSING SERVICES	2,611.13
05/26/2020	2912(A)	ETNA SUPPLY	STREET FLOODING	1,097.22
05/26/2020	2913(A)	FLEIS & VANDENBRINK ENGINEERING IN	ENGINEERING FEES	2,234.84
05/26/2020	2914(A)	HOLLAND LITHO PRINTING SERVICE	OVAL BEACH	741.49
05/26/2020	2915(A)	HOLLAND P.T.	STREET FLOODING	125.93
05/26/2020	2916(A)	K&R TRUCK SALES INC	TRUCK REPAIR	215.35
05/26/2020	2917(A)	MICHIGAN ELECTRO FREEZE INC	CONCESSION	1,231.00
05/26/2020	2918(A)	MICHIGAN WOOD FIBERS	PARK MULCH	573.75
05/26/2020	2919(A)	PRO-TEMP INC	CONCESSION	416.53
05/26/2020	2920(A)	PURITY CYLINDER GASES INC	CONCESSION	63.05
05/26/2020	2921(A)	SEPTIC TANK SYSTEMS CO INC	BUTLER STREET	275.00
05/26/2020	2922(A)	SMART BUSINESS SOURCE LLC	OFFICE SUPPLIES	550.15
05/26/2020	2923(A)	WEST MICHIGAN UNIFORMS	COVID MASK	456.00
05/26/2020	16444	CITY OF SOUTH HAVEN	SIGNS	193.68
05/26/2020	16445	DEVELONET	WEBSITE	1,100.00
05/26/2020	16446	GREAT LAKES ORNAMENTALS	PARKWAY TREES	412.00
05/26/2020	16447	IHLE AUTO PARTS	PARTS & OIL	116.95
05/26/2020	16448	LEE'S TRENCHING	STREET CUT REFUND 645 LAKE S	1,500.00
05/26/2020	16449	MINER SUPPLY CO	SUPPLIES	81.88
05/26/2020	16451	QUALITY DOOR COMPANY INC	DPW DOOR REPAIR	78.00
05/26/2020	16452	RATHCO SAFETY SUPPLY CO	SIGNS	89.02
05/26/2020	16453	SPRING BROOK SUPPLY	PARKS REPAIRS	97.62

06/04/2020		CHECK REGISTER FOR CITY OF SAUGATUCK		
		CHECK DATE FROM 05/01/2020 - 05/31/2020		
Check Date	Check	Vendor Name	Description	Amount
05/26/2020	16454	WYOMING ASPHALT PAVING CO	ASPHALT	442.75
05/26/2020	2904(E)	COMCAST	TELEPHONES & INTERNET	284.60
05/26/2020	2905(E)	CONSUMERS ENERGY	ELECTRIC	752.87
05/26/2020	2906(E)	PRIORITY HEALTH	HEALTH INSURANCE	5,915.26
05/29/2020	DD4465(A)	BOSCH, LEXIE	PAYROLL	226.20
05/29/2020	DD4466(A)	BULTMAN, LINDA	PAYROLL	1,264.10
05/29/2020	DD4467(A)	DEROO, MADYSON	PAYROLL	328.29
05/29/2020	DD4468(A)	ELLISON, KATE	PAYROLL	234.86
05/29/2020	DD4469(A)	GOODRICH, RICHARD	PAYROLL	826.46
05/29/2020	DD4470(A)	HARRIER, KIRK	PAYROLL	2,158.50
05/29/2020	DD4471(A)	HERBERT, SCOTT	PAYROLL	1,586.64
05/29/2020	DD4472(A)	ILMBERGER, MACY	PAYROLL	155.69
05/29/2020	DD4473(A)	KAZDA, NATHAN	PAYROLL	1,136.49
05/29/2020	DD4474(A)	KERRIDGE, ADAM	PAYROLL	1,122.90
05/29/2020	DD4475(A)	KERRIDGE, LUCAS	PAYROLL	96.90
05/29/2020	DD4476(A)	NAGEL, MONICA	PAYROLL	1,568.85
05/29/2020	DD4477(A)	NYBOER, KARSYN	PAYROLL	125.53
05/29/2020	DD4478(A)	OSMAN, CINDY	PAYROLL	1,405.23
05/29/2020	DD4479(A)	STANISLAWSKI, PETER	PAYROLL	1,400.43
05/29/2020	DD4480(A)	WEBSTER, MARY	PAYROLL	42.28
05/29/2020	DD4481(A)	WENDT, MICHAEL	PAYROLL	1,201.32
05/29/2020	EFT1290(E)	457-VALIC	PAYROLL	3,721.21
05/29/2020	EFT1291(E)	STATE OF MICHIGAN	PAYROLL	185.06
05/29/2020	EFT1292(E)	MERS HYBRID	PAYROLL	1,193.26
05/29/2020	EFT1293(E)	FEDERAL TAX DEPOSIT	PAYROLL	5,407.14
05/29/2020	EFT1294(E)	MERS	PAYROLL	5,061.05
05/29/2020	EFT1295(E)	MI DEPT OF TREASURY	PAYROLL	2,237.29
05/31/2020	2924(E)	AT&T MOBILITY	CELL PHONES	155.70
05/31/2020	2925(E)	MICHIGAN GAS UTILITIES	CITY HALL	61.81
05/31/2020	2926(E)	MICHIGAN GAS UTILITIES	BUTLER STREET	67.49
05/31/2020	2927(E)	MICHIGAN GAS UTILITIES	DPW GARAGE	62.34
Total of 115 Checks:				184,296.34
Less 0 Void Checks:				0.00
Total of 115 Disbursements:				184,296.34

Item **10.A**

City Council
Agenda Item Report

City of Saugatuck

FROM: Cindy Osman, Planning and Zoning

MEETING DATE: **Introduction:** June 8, 2020
Action Date: June 22, 2020

SUBJECT: Introduction of Ordinance amendment to Section 154.005 definitions, 154.024 C-1 City Center Commercial District (CC), 154.039; C-2 Water Street East Direct (WSE), 154.040 C-1 Water Street North District (WSN), 154.041 C-2 Water Street South District (WSS)

DESCRIPTION
To clarify the definitions of business offices, and personal service establishments, to limit business offices to second and third floors in the downtown commercial zone districts, and to make restaurants consistently special land uses throughout the different commercial zone districts.

BUDGET ACTION REQUIRED
N/A

COMMITTEE/COMMISSION REVIEW
Planning Commission unanimously voted to recommend Council adoption on June 22, 2020.

LEGAL REVIEW
Municipal Attorney Jeff Sluggett has reviewed the amendment and prepared the attached Ordinance amendment.

SAMPLE MOTION:
Motion to place the proposed Ordinance amendment to amend those Sections 154.041, Chapter 154, Title XV, of the Code of the City of Saugatuck, entitled "Land Usage; Zoning Code section 154.005, 154.024, 154.039, 154.040, and 154.041 on the June 22, 2020 regular council meeting agenda for action.

CITY COUNCIL
CITY OF SAUGATUCK
ALLEGAN COUNTY, MICHIGAN

ORDINANCE NO. _______-__

AN ORDINANCE TO AMEND TITLE XV, CHAPTER 154, SECTIONS 154.005, 154.024, 154.039, 154.040, AND 154.041 OF THE CODE OF THE CITY OF SAUGATUCK

The City of Saugatuck Ordains:

Section 1. Amendment of Section 154.005. That Section 154.005, Chapter 154, Title XV, of the Code of the City of Saugatuck, entitled "Land Usage; Zoning Code; Definitions" is amended with respect to the following definitions:

BUSINESS, PROFESSIONAL OFFICES. A building, or portion of a building, occupied by an establishment in which a person or persons offer a ~~service that does not include a tangible product~~professional service for a fee or charge including but not limited to: offices for finance, insurance and real estate functions, legal services, engineering, architectural and planning services, accounting, auditing and bookkeeping services.

PERSONAL SERVICE ESTABLISHMENTS. A building, or portion of a building, occupied by an establishment in which a person, or persons, ~~practices a vocation that performs a type of labor, act or work that results primarily in a specialized aid or assistance~~ offers a service directly to the personal needs of ~~ultimate~~ consumers normally served on the premises for a fee or charge. The type of specialized aid or assistance provided by a personal service establishment includes but is not limited to the following: beauty and barber services, ~~garment mending, alteration and related minor pressing services, shoe shining, shoe repair and hat cleaning services; watch, clock and other personal services of a similar nature. ***PERSONAL SERVICE ESTABLISHMENTS*** do not include laundry and dry-cleaning plants.~~spa services, dance and yoga classes, and tattoo parlors. Personal service establishments do not include professional offices.

Section 2. Amendment of Section 154.024. That Section 154.024, Chapter 154, Title XV, of the Code of the City of Saugatuck, entitled "Land Usage; Zoning Code; C-1 City Center Commercial District (CC)" is amended to read as follows:

154.024 C-1 CITY CENTER COMMERCIAL DISTRICT (CC).

(A) *Generally*.

(1) This district is designed to promote and preserve the Central Business District character of the city.

(2) The district permits intense retail and commercial uses.

(3) Residential uses are encouraged on the second and third floors of buildings in the district.

(4) Utilization of existing undeveloped land in the district is encouraged when done in a manner consistent with the character of the district.

(B) *Permitted uses*:

(1) Essential public services;

(2) Retail stores;

(3) Domestic and business repairs;

(4) Personal service establishment;

(5) Art gallery;

(6) Single-family, two-family, multiple-family dwelling units on second or third floors;

(7) Home occupations; ~~and~~

(8) Short-term rental unit on second or third floors~~.~~; and,

(9) Business, Professional Offices on second and floors only.

(C) *Special land uses*. Special land uses are subject to review and approval by the Planning Commission in accordance with §§ 154.060 through 154.068 and §§ 154.080 through 154.092:

(1) Bed and breakfast;

(2) Hotel/inn;

(3) Motel/motor court;

(4) Motion picture facility;

(5) Parking facility;

(6) ~~Restaurants~~Restaurant;

(7) Rental of accessory dwellings;

(8) Recreational transportation rental facilities; and

(9) Brewery, distillery, and winery.

(D) *Dimension and area regulations*.

(1) Permitted uses and special uses: 4. Motion picture facility, 5. Parking facility, 6. Restaurants, 8. Recreational transportation rental facilities, and 9. Brewery, distillery, and winery.

Front setback	0 feet
Side setback	0 feet*
Rear setback	0 feet*
Minimum lot area	4,356 square feet
Minimum lot width	33 feet of street frontage
Maximum lot coverage	100%*
* Subject to Fire Code Regulations	

(2) Special uses: 1. Bed and breakfast, 2. Hotel/inn, 3. Motel/motor court, and 7. Rental of accessory dwellings.

Front setback	0 feet
Side setback	0 feet *
Rear setback	0 feet *
Minimum lot area	8,712 square feet
Minimum lot width	66 feet
Maximum lot coverage	100%
* Subject to Fire Code Regulations	

Section 3. <u>Amendment of Section 154.039</u>. That Section 154.039, Chapter 154, Title XV, of the Code of the City of Saugatuck, entitled "Land Usage; Zoning Code; C-2 Water Street East Direct (WSE)" is amended to read as follows:

§ 154.039 C-2 WATER STREET EAST DISTRICT (WSE).

(A) *Generally*. The Water Street East District is designed to preserve the residential flavor of the area while promoting commercial land use and development. The district is designed for an intermediate intensity and density of structures and land use. Commercial development is desired in this district. The district will also promote visual access to the Kalamazoo River and lake.

(B) *Permitted uses*:

(1) Essential public services;

(2) Retail stores;

(3) Domestic business repairs;

(4) Personal service establishment;

(5) Art gallery;

~~(6) Restaurants;~~

~~(7~~(6) Dwelling, single-family detached;

(~~8~~7) Second- and third-floor apartments; ~~and~~

~~(9~~ (8) Short-term rental unit on second and third floors; and.

(9) Business, Professional Offices on second and third floors only.

(C) *Special uses*. Special land uses are subject to review and approval by the Planning Commission in accordance with §§ 154.060 through 154.068 and §§ 154.080 through 154.092:

(1) Hotel/inn;

(2) Motel/motor court;

(3) Motion picture facilities;

(4) Amusement and recreation services;

(5) Recreational transportation rental facilities; ~~and~~

(6) Parking facilities~~.~~; and

(7) Restaurant.

(D) *Dimension and area regulations:*

(1) Permitted uses (except as noted) and special uses: 4. Amusement and recreation services and 5. Recreational transportation rental facilities.

Front setback	0 feet

Side setbacks	10 feet
Rear setback	10 feet
Minimum lot area	4,356 square feet
Maximum lot coverage	65%

(2) Special uses: 1. Hotel/inn, 2. Motel/motor court, 3. Motion picture facilities, and 8. Dwelling unit, single-family detached.

Front setback	0 feet
Side setback	10 feet
Rear setback	10 feet
Minimum lot area	8,712 square feet
Minimum lot width	66 feet
Maximum lot coverage	65%
*Front setback shall be 10 feet for single-family dwellings	

Section 4. Amendment of Section 154.040. That Section 154.040, Chapter 154, Title XV, of the Code of the City of Saugatuck, entitled " Land Usage; Zoning Code; C-1 Water Street North District (WSN)" is amended to read as follows:

154.040 C-1 WATER STREET NORTH DISTRICT (WSN).

(A) *Generally*. Water Street North District is designed to promote high intensity commercial uses that complement its waterfront setting. This district will promote visual access to the Kalamazoo River and Lake to coordinate with the commercial uses of the district. The purpose of the district is to promote a more intense commercial use and encourage development of similar businesses and land uses in the district.

(B) *Permitted uses*:

(1) Dwelling, single-family detached;

(2) Dwelling unit, two-family;

(3) Essential public services;

(4) Retail stores;

(5) Domestic business repairs;

(6) Personal service establishments;

(7) Art gallery;

(8) Marinas/commercial boats;

(9) Second- and third-floor apartments;

(10) Charter fishing/tours;

(11) Home occupations; ~~and~~

(12) Short-term rental unit~~.~~; and

(13) Business, Professional Offices on second and third floors only.

(C) *Special land uses*. Special land uses are subject to review and approval by the Planning Commission in accordance with §§ 154.060 through 154.068 and §§ 154.080 through 154.092:

(1) Bed and breakfasts;

(2) Hotel/inn;

(3) Motel/motor court;

(4) Restaurants;

(5) Home businesses;

(6) Recreational transportation rental facilities; and

(7) Parking facilities.

(D) *Dimension and area regulations*:

(1) Permitted non-residential uses and special uses: 4. Restaurants and 6. Recreational transportation rental facilities.

Front setback	0 feet
Side setbacks	0 feet*
Rear setback	0 feet*
Minimum lot	4,560 square feet
Minimum lot width	66 feet

Maximum lot coverage	100%*
* Subject to Fire Code Regulations	

(2) Single-family dwellings, two-family dwellings, and special use: 5. Home businesses.

Front setback	15 feet
Side setbacks	5 feet
Rear setback	10 feet
Minimum lot area	6,600 square feet
Minimum lot width	66 feet
Maximum lot coverage	50%

(3) Special uses: 1. Bed and breakfast, 2. Hotel/inn, and 3. Motel/motor court.

-	
Front setback	0 feet
Side setback	0 feet*
Rear setback	0 feet*
Minimum lot area	8,712 square feet
Minimum lot width	66 feet
Maximum lot coverage	50%
* Subject to Fire Code Regulations	

Section 5. Amendment of Section 154.041. That Section 154.041, Chapter 154, Title XV, of the Code of the City of Saugatuck, entitled "Land Usage; Zoning Code; C-2 Water Street South District (WSS)" is amended to read as follows:

154.041 C-2 WATER STREET SOUTH DISTRICT (WSS).

(A) *Generally*. This district will provide an area for waterfront retail and commercial land use. The Water Street South District will provide for a less intense commercial use than the City Center District and promote visual access to the Kalamazoo River. The intent of the district is to coordinate the aspects of a central business district with that of waterfront property and blend commercial uses that complement and enhance the waterfront.

(B) *Permitted uses*:

(1) Essential public services;

(2) Retail stores;

(3) Bed and breakfasts;

(4) Domestic and business repairs;

(5) Personal service establishments;

(6) Art gallery;

(7) Restaurants;

(8(7) Business, professional offices;

(98) Parks;

(10 (9) Dwelling, single-family detached;

(11 (10) Second- and third-floor apartments;

(12 (11) Home occupations; and,

(13 (12) Short-term rental unit on second or third floors.

(C) *Special land uses*. Special land uses are subject to review and approval by the Planning Commission in accordance with §§ 154.060 through 154.068 and §§ 154.080 through 154.092:

(1) Hotel/inn;

(2) Motel/motor court;

(3) Motion picture facilities;

(4) Marina commercial/private;

(5) Community center;

(6) Club and fraternal organization;

(7) Amusement and recreational services;

(8) Recreational transportation rental facilities; and

(9) Parking facilities.; and,

(10) Restaurants.

(D) *Dimension and area regulations*:

(1) Permitted uses and special uses: 5. Community center, 6. Club and fraternal organization, 7. Amusement and recreational services, and 8. Recreational transportation rental facilities.

-	
Front setback	0 feet
Side setback	10 feet
Rear setback	15 feet
Minimum lot area	6,600 square feet
Minimum lot width	66 feet of street frontage
Maximum lot depth	100 feet
Maximum lot coverage	45%

(2) Special uses: 1. Hotel/inn, 2. Motel/motor court, 3. Motion picture facility, and 4. Marina commercial/private:

Front setback	0 feet
Side setback	10 feet
Rear setback	15 feet
Minimum lot area	13,200 square feet
Minimum lot width	132 feet
Minimum lot depth	100 feet
Maximum lot coverage	45%

Section 6. Effective Date. This Ordinance shall become effective seven (7) days after its publication unless otherwise provided by law.

YEAS:____________________________________

NAYS: ____________________________________

ABSENT: ____

ORDINANCE NO. ___________ ADOPTED

I, _____________, certify that the foregoing is a true and accurate copy of an ordinance adopted at a regular meeting of the City Council of the City of Saugatuck, held on __________, 2020, and noticed in accordance with all legal requirements.

____
______________, Clerk

Introduced: _______________
Adopted: _________________
Published: ________________

Item 13.A

City Council
Agenda Item Report

City of Saugatuck

FROM: Kirk Harrier, City Manager

MEETING DATE: June 8, 2020

SUBJECT: Interim City Clerk Appointment

DESCRIPTION

The City Clerk position is currently vacant and the City Manager is conducting a search to fill the position. Section 6.3 of the Saugatuck City Charter states, the City Manager shall make all appointments and removals of those appointed (staff), except he shall receive the approval of a majority of the Council for the appointment of the clerk, treasurer and assessor." I am appointing the City of Saugatuck Planning/Zoning Administrator, Ms. Cindy Osman, to serve as interim City Clerk until the position is filled. This appointment however is required to receive approval form a majority of Council. Ms. Osman served as an election precinct chairperson for the City Holland and worked many elections there so she already has a basis fundamental knowledge that will be helpful in this temporary transition.

BUDGET ACTION REQUIRED

N/A

COMMITTEE/COMMISSION REVIEW

N/A

LEGAL REVIEW

Municipal Attorney Jeff Sluggett has reviewed the appointment language in the City Charter and confirms the appointment process is appropriate.

SAMPLE MOTION:

Motion to **approve/deny** the City Manager's appointment of Cindy Osman to serve as interim City Clerk.

Memo

To: Saugatuck City Council

From: Kirk Harrier—City Manager

Date: June 4, 2020

Re: Kalamazoo Harbor Invasive Species (Eurasian Water Milfoil)

The City Council has been discussing the problem with Eurasian Water Milfoil in the Kalamazoo Harbor for some time; specifically an area just north of the Blue Star Bridge as shown in the photo below.

Eurasian Water Milfoil is aggressive and invasive. The vast majority of waterfront property owners up stream along the Kalamazoo River are simply cutting the offending vegetation which then spreads it down river to the Saugatuck/Douglas location. Boats also spread the vegetation. In 2019 staff solicited bids from six (6) different chemical contractors to submit proposals for a one-time treatment. The City received two bids which are attached to this report.

- Clarke Aquatic Services bid for chemical treatment was $1,200 per acre with an estimated treatment area of 11.5 acres ($13,800). The City would also be responsible for obtaining the required authorization forms from each property owner in the treatment area and paying the fee for the State of Michigan permit ($408). Total cost <u>$14,208.</u>

- Aquatic Doctors bid for chemical treatment listed a number of different chemical treatment options and costs. However if the City is interested in just treating the Eurasian Water Milfoil they recommend using the Navigate granular herbicide which is $315 per acre. 11.5 acres would cost $3,622. The City would also be responsible for obtaining the required authorization forms from each property owner in the treatment area paying the fee for the State of Michigan permit, which is assumed to be the same costs as identified by Clarke Aquatic Services ($408). Total cost <u>$4,030.</u>

The City never moved forward with treatment due to a few reasons (as I recall) noted below. Discussions regarding the matter simply lost momentum due to the many other pressing priority issues Council had/has on the docket.

1.) The two bids received had a substantial difference in pricing and the City was unable to receive confirmation regarding the pricing spread to determine if the low bid was worth completing or would provide less than desirable results compared to the more expensive option.

2.) Funding, i.e. should treatment be financed via a special assessment so the property owners that benefit the most have the most responsibility or should treatment options be paid for through general property tax revenues consisting of all the properties in the City, not just waterfront.

2.) Some residents raised issues with using chemicals in the waterway for invasive species treatment and suggested using a non-chemical approach such as weevils; which has been verified as having some success in studies.

3.) The City received conflicting information on the best treatment approach. Some experts said chemical treatment was the best and others said physically cutting was the best.

4.) The Outdoor Discovery Center was consulted and they stated they would not recommend treating vegetation with herbicide/algaecide as those treatments require a granular (solid) which sinks to the root zone of these plants and slowly dissolves thus killing the submerged vegetation. Being in a riparian system like the Kalamazoo River, this method runs the risk of significant off target kill dependent on currents. The Outdoor Discovery Center has attempted milfoil granular treatments in Kalamazoo River in the past and said they have had very moderate success.

3.) Dr. Bob Shuchman, the Co-Director at Michigan Tech Research Institute put the City in contact with a researcher, Colin Brooks, who performed some extensive research on Eurasian Water Milfoil through Michigan Technological University (report attached). Mr. Brooks stated chemical treatment of Eurasian Water Milfoil comes back very quickly, often times within a month or two. A small fragment of milfoil will establish and most of the issues in Saugatuck Harbor are from contamination up river which makes it difficult and expensive to control. Mr. Brooks stated the best success so far he has seen is the use of DASH (diver assisted suction harvesting) which produces less fragmentation. However it is the most expensive approach.

Clarke Aquatic Services, Inc.
Professional Services Agreement For
2019 For The City of Saugatuck
Integrated Aquatics Management Program

Clarke Aquatic Services, Inc. (Clarke) will provide an aquatic weed control program for the lake(s) named below subject to the conditions listed below.

The City of Saugatuck, Saugatuck Michigan

A. Program Details

- ***Nuisance plant control program for The City of Saugatuck.***
- ***Treatment each season shall be performed between Mid-April through September as requested by the City of Saugatuck.***
- ***Payment will be due upon completion of the treatment.***

B. Additional Program Information

Clarke's customized water management plan includes eight inspection, assessment, recommendations, implementation, and customized reports. This integrated approach uses a maximum number of inspections to keep the pond as healthy and balanced as possible Clarke will determine the proper treatment program at the time of inspection based on the weather and environmental conditions of the water. All Clarke products used are EPA registered and labeled for aquatic use and permitted by the State.

Treatment of vallisneria, hydrilla, duckweed or cabomba is not guaranteed unless specifically addressed above in "Program Details." Treatment will also not be effective against emergent plants (Lily pads, cattails etc.) or copper resistant algae. Re-growth of weeds and algae may occur later in the season and Clarke cannot be held responsible for re-growth of weeds and algae. Program does not include removal of plant material.

C. Customer Responsibilities

The area customer must take responsibility for passing out notification to residents within 100 feet of the treatment areas at least seven (7) days prior to the estimated treatment date. Notifications will be forwarded to the area coordinator three (3) weeks prior to treatment.

It is required by the Michigan Department of Environmental Quality that permission be obtained from lakefront property owners for treatment of their bottomland property.

D. Agreement Term and Termination

The term of the Professional Services Agreement shall commence on the signature date and shall continue for a period ending on December 31, 2019. If a party hereto fails to comply with a provision of this Agreement, then the other party shall have the right to terminate this Agreement if it gives written notice of the default to the defaulting party and the defaulting party fails to cure the default within sixty days of receipt of said notice.

E. Program Pricing and Payment

1. Pricing for treatment of aquatic vegetation (Eurasian Water Milfoil) for the City of Saugatuck. Current acreage is estimated at 11.5 acres in the two areas surveyed. In the event these areas expand the cost per acre will be $1,200.00. Due to the flow in the area we are recommending using a rate of 4ppm as suggested on the label for flowing waters.

2. The cost will include posting, permit preparation (if required), purchase of chemicals, and their application. Weed treatments must be done in conjunction with an algae treatment. All work to be completed in a workman-like manner in accordance with accepted lake management practices. Critical and unforeseeable factors beyond our control prevent us from eliminating all risk in the use of chemicals; therefore, any warranty, except as stated, shall be limited to that provided by the manufacturer of the product(s) used.

3. ***The customer is responsible for the permit fee of $408.00 to the State of MI. Clarke Aquatic Services will pay the permit fee and add the cost to the invoice, if so requested by the customer.***

E. Liability, Damage, and Confidentiality Clauses

1. Clarke Aquatic Services shall not be responsible or liable for any personal injury and/or property damage resulting from drinking, use of, or exposure to chemically treated water. Allegations of property damage resulting from scheduled Clarke service must be submitted in a written report and filed directly with respective Aquatic Specialist within thirty (30) business days. The Clarke Aquatic Services team will review the report, determine a fair and equitable resolution, and respond within a timely manner.

2. This contract is subject to and conditioned upon issuance of necessary and appropriate permits. While Clarke Aquatic Services will promptly apply for same, issuance is uncertain and in the event the permit is not granted, this contract may be canceled at Clarke Aquatic Services' option. In the event this contract shall be canceled due to the unavailability of a permit, no damages shall be assessed due to such a cancellation.

3. This contract, including any additional information provided, contains confidential information. It is intended solely for the use of the individual or entity to whom it is addressed and others authorized to receive it. If you are not the intended recipient, you are hereby notified that any disclosure, copying, distribution or taking any action in reliance on the contents of this information is strictly prohibited.

SIGNING AND RETURNING this document will authorize Clarke Aquatic Services to perform the services stipulated within the limits of this contract unless otherwise stated.

______________________	__________	Luke Britton	7-29-19
	Date		Date
City of Saugatuck		Luke Britton Water Resource Manager, Midwest Clarke Aquatic Services, Inc.	

City of Saugatuck

PLEASE ASSIST US IN MAINTAINING OUR RECORDS BY COMPLETING THE FOLLOWING:

BILLING ADDRESS:

Name: ____

Name of Property Management firm (if applicable): ______________________________

Address: ____

City: ______________________________ State: __________ Zip: __________

Phone: ______________________________ Fax: ______________________________

Accounts Payable E-mail: ____

CONTACT PERSON FOR LAKE (if different from above):

Contact Name: ____

Address: ____

City: ______________________________ State: __________ Zip: __________

Phone: ______________________________ Fax: ______________________________

E-mail: ____

ALTERNATE CONTACT PERSON FOR LAKE:

Name: ______________________________ Title: ______________________________

Phone: ______________________________ Fax: ______________________________

E-mail: ____

INSPECTION REPORTS:

Email service reports to the following email addresses:

❑ Email: ____

❑ Email: ____

Please sign and return a copy of this completed contract to:
Clarke Aquatic Services
Attention: **Luke Britton**
P.O. Box 121
Spring Lake, MI 49456
Phone: 616-638-6794
Fax: 630-443-3070
Lbritton@clarke.com

AQUATIC DOCTORS LAKE MANAGEMENT, INC. ("Aqua Docs") of P.O. Box 150247, Grand Rapids, Michigan 49515 and City of Saugatuck of Saugatuck, Michigan agree:

Aqua Docs will provide a professional aquatic program for the control of weeds and/or algae in **Kalamazoo Harbor**. The program will consist of the following:

May/June: Weed and Algae treatment applying restrictive products such as Navigate (2,4-D), Diquat, Triclopyr, Aquathol K, Hydrothol 191, and non-water restrictive products such as copper sulfate, Cutrine-Plus, Cutrine-Ultra, Cygnet Plus, and shade as a tracer.
**3-4 weeks after initial treatment- spot treat weed beds and algae treatment.

July and August: Algae treatments applying non-water restrictive products such as copper sulfate, Cutrine-Plus, Cutrine-Ultra, Cygnet Plus and shade as a tracer. Spot weed treatment for EWM and other nuisance plant growth.

Cost per Acre:

Navigate: Granular systemic 2,4-D herbicide to control Eurasian Watermilfoil	$ 315.00
Triclopyr: Granular systemic herbicide to control Eurasian	$ 560.00
Triclopyr: Liquid systemic herbicide to control EWM	$ 285.00
Clipper: systemic herbicide to control Starry Stonewort	$ 575.00
Harpoon: granular systemic herbicide to contro Starry Stonewort	$ 425.00
Diquat: Liquid herbicide to control EWM, Curlyleaf, and Pondweeds	$ 185.00
Aquathol K-Hydrothol 191: Liquid herbicide to control Pondweeds	$ 205.00
Algaecides: Granular products to control Chara	$ 50.00
Algaecides: Granular and liquid products to control algae	$ 40.00
Water Quality Program:	$ 50.00/sample

Description and Optional Services:

Weed Treatment: Milfoil, Curly-leaf, Coon-tail, Chara, and various pondweed treatments applying restrictive products such as granular Navigate (2,4-D), Aquathol K, Hydrothol 191, Diquat, Triclopyr, Komeen, Glyphosate, and Cygnet Plus.

Algae treatment: Non-water restrictive algaecides such as Copper Sulfate, Curtain-Plus, Cutrine-Ultra, Chelated Copper, Earthtech, Greenclean, and shade as a tracer. Treatments should occur monthly to prevent existing growth and prevent re-growth. Surrounding conditions (i.e. sunlight, temperature, nutrient concentration, etc…) may require additional treatments.

Muck/Enzyme Treatment: Designed to decrease levels of organic sediment in lakes and ponds while reducing odors and improving water clarity. The pellets sink quickly, targeting 'muck' on the bottom. Mukk Busster does not contain pathogenic bacteria and it is fish and wildlife friendly. Contains 3 billion CFU/gram (Colony-forming units).

Water Quality Program: Water quality program consists of lake samples taken and sent to an independent laboratory (Prein & Newhof). The samples can be tested for a variety of things including; fecal bacteria (E. coli), dissolved oxygen, conductivity, total dissovled solids, pH and alkalinity. Primarily E. coli is the focus.

- Specific treatment dates will be set by Aqua Docs, in cooperation with Kirk Harrier.
- Please be aware Aqua Docs can only treat weeds and algae present at the time of treatment. We have no control over future weed or algae growth based on the current chemicals registered for aquatic use in Michigan.
- Unless otherwise stated in the program, all other aquatic pest control will require a separate program (i.e. cattails, duckweed, largeleaf pondweed, lily pads, purple loosestrife, watermeal, etc…)

Aqua Docs will obtain the DEQ "Aquatic Nuisance Control permit" and post restriction signs as required. Any facility or location related permits/requirements, for example, "Discharge or Retention" permits will be the responsibility of the customer, association, resident or facility. It is your association's/group's responsibility to notify each resident within one hundred (100) feet of the treatment area at least seven (7) days in advance of the first treatment that chemicals will be applied. This notification requirement must be provided to every property owner who has consented to have their property treated. Lake boards and townships who assess the lake property owners are exempt from individual consent documentation. The property owner is responsible for removing any restriction signs ten (10) days after the conclusion of water use restrictions.

Aqua Docs carries a general liability policy of insurance for workmans comp, bodily injury and property damage with limits of $1,000,000.00 per occurrence. Certificates of insurance will be provided upon request.

The State of Michigan requires a minimum fee of $75.00 and increases the fee to $1500.00 for treatment areas of 100 acres or more. Please make check to the State of Michigan. Application for the DEQ "Aquatic Nuisance Control permit" shall occur promptly after the fee is received from the customer.

Special Notes & Conditions of Treatments

#1 – Our office must be notified of any inlets/outlets to meet specific permit requirements with the Michigan DEQ.
#2 – If the water body is being used as a source of irrigation, please notify our office prior to any treatments.
#3 – To minimize the possible effects on health and the environment, the treated waters MAY be restricted for such uses as swimming, bathing, irrigation, fish consumption and/or livestock.
#4 – If an access site has not been determined or established prior to services rendered, then an access site must be determined at the discretion of the applicator at the time of treatment.

Payment in full is due within fifteen (15) days of each application. Any amount remaining unpaid when due shall accrue a penalty of 1.5% per month.

All materials utilized by Aqua Docs shall be of the highest quality and are registered with the U.S. Environmental Protection Agency and the Michigan Department of Agriculture.

The accumulation of dying and decomposing plants and algae can deplete the dissolved oxygen supply in the water, which may result in fish mortality. Please note that such occurrences are minimal, however, the possibility does exist. Due to their level of sensitivity, Goldfish, Coy, and Trout are more susceptible to a treatment than other fish species. During Late Spring and Summer, many NATURAL fish kills occur due to an increase in water temperature and spawning habits, primarily.

Three or five year treatment program: As an incentive to establish a multiple year agreement we will treat your lake or pond at the same price structure as 2019 for 2020! The remaining years (2021-2023) will have cost increases of three percent or less. If total chemical costs exceeds 10% from the previous year a new agreement will have to be mutually acceptable. If during the life of the contract the DNR or other regulatory agencies significantly change the approved treatment procedures or the client finds the manner in which the work is performed less than satisfactory, either party may terminate this agreement upon giving ninety (90) days advance written notice thereof.

Contract:

Signature Page for "<u>City of Saugatuck</u>"

Program Option for City of Saugatuck:

One (1) Year Program- _______
Three (3) Year Program- _______
Five (5) Year Program- _______
(Just initial your choice)

Aquatic Doctors Lake Management, Inc.

By: MT Ryan Schauland B.S.
President

_________________________ _______________
Signature Date

For City of Saugatuck Representative:

Name (Print) ____________________ _________________________
Title ____________________ Signature
Address: ____________________
____________________ _______________
Phone: Date
(Day): ____________________
(Eve): ____________________ email: ____________________

STATE:	Michigan
GRANT TITLE:	Innovative and multifaceted control of invasive Eurasian and hybrid watermilfoil using integrative pest management principles
REPORT TYPE:	Final Performance Report
DATE:	Aug 29, 2018

Final Summary

The goals of this project were to better detect and predict invasions of Eurasian Watermilfoil, analyze watermilfoil genetic diversity and its linkage to efficacy of control, and explore alternative treatment approaches, all of which will guide management strategies for the control of invasive watermilfoil. The primary approach employed to control Eurasian Watermilfoil in Michigan is the application of herbicides, which are costly and have potential indirect effects on the ecosystem that are largely unknown. Eurasian Watermilfoil can hybridize with native watermilfoils resulting in hybrids that may be less sensitive to herbicide treatment. Variation in the genetic composition of watermilfoil individuals (i.e., their genotype) may thus influence their response to treatment. In this project our team of university researchers, professional lake managers, and herbicide specialists demonstrated that fewer different genotypes of invasive watermilfoil (i.e., lower diversities) were observed in 7 Michigan lakes with a history of herbicide treatment as compared to 4 lakes that did not have a history of herbicide treatment in the five years preceding our study, and that the genotypes in herbicide treated waters were considerable more admixed (i.e., of hybrid origin). In general, we found low genetic diversity in the lakes we studied, which is a common observation for macrophytes. Although we detected variation in sensitivity to three different herbicides (2,4-D, Triclopyr, and Fluridone) by some watermilfoil individuals within a waterbody, that variation was not significantly explained by genotype or genotype class (hybrid or not). However, sensitivity to 2 of the 3 herbicides examined did relate to the history of herbicide treatment in the waterbodies with individuals from herbicide treated lakes showing less susceptibility to herbicides. We examined the feasibility of alternative control measures such as growing mats of native aquatic macrophytes to be planted as a post treatment approach to rehabilitate the area. Although this approach has worked in other systems (e.g., sea grass restoration) we were unable to develop mats of sufficient integrity and plant density to be useful. However, our evaluation of Diver Assisted Suction Harvesting (DASH) to manage small patches of invasive submerged aquatic plants suggests promise. Initial results show it is an effective method of selectively removing watermillfoil and we are in the process of examining the long-term efficacy. Given these difficulties in controlling watermilfoil once it has invaded, prevention and early detection are thus important areas of focus, and we have made great progress toward developing remote approaches to detect watermilfoil using satellite imagery and unmanned aerial vehicles equipped with various optical sensors. These monitoring approaches could be employed to survey lakes with boat launches and in close proximity to other invaded lakes, which have a high threat of invasion by watermilfoil as highlighted by our modeling efforts. We have conducted active outreach to Michigan school districts and the general public through informational events and our Eurasian Watermilfoil web page with the goal of increasing awareness among the general public of issues related to invasive species and recognizing them in the environment.

Discussion of Accomplishments

1. Tasks completed and the progress made

Objective 1 - Retrospective Analysis:

- The primary goal of this objective was to gather existing survey data of submerged aquatic plants in inland Michigan lakes for analysis of baseline community structure and composition in the region as well as before and after herbicide treatments of lakes invaded by Eurasian watermilfoil. Through the process of working with DEQ ANC staff during the life of this project, we have acquired the ANC dataset with all the plant survey data. For the analysis as planned we also needed the treatment data for the lakes within the DEQ permit database. After working with the

DEQ and submitting the FOI request for this data, we received the treatment reports for the years 2007-2015. We also now have the permit list that includes identifying codes needed to link all these data for a given waterbody. To complete this project we will continue to work closely with DEQ staff to both conduct analysis pertinent to their needs and more efficiently integrate the various databases developed by the DEQ.

Objective 2 – Milfoil genotype diversity and patterns of hybridization in relation to herbicide sensitivity.

- We have finished processing and analyzing samples for ploidy determination and microsatellite genetic profiling and have completed herbicide sensitivity assays.

- **Genetic *Analysis***: In total we genotyped 1362 plants (675 from areas with a history of treatment and 687 from areas our data suggests no history of treatment) at 12 microsatellite markers from 10 main "areas" including two areas in the Keweenaw Waterway of the Upper Peninsula of Michigan and 8 Lower Michigan Lakes. We have also genotyped roughly 30 individuals from additional waterways including samples from Lake Michigan near Escanaba and Lake Huron in the Les Cheneaux Islands area to expand our sampling efforts and to obtain a broader sampling of introduced and native species genotypes. All 12 markers were polymorphic (with 2 to 11 unique alleles per locus) and were used to determine multilocus genotypes. In general, we found low overall genotype and genetic diversity among our samples, a feature that has commonly been reported for macrophytes. Due to initial detection of low genotype diversity and the observation that samples were polyploids (see below) – both of which reduce power to examine genetic diversity, admixture, and population structure, we increased our sample size to include more individuals to screen for nuclear variation. In total, from the 1362 plants, we found 99 unique invasive watermilfoil genotypes and all genotypes were exclusive to a single waterbody with the exception of one overlapping genotype that occurred in two waterbodies. Comparison of genotype diversity among lakes found that lakes with a history of previous treatment had lower genotypic diversity (average number of genotypes = 4) as compared to lakes with no history of treatment (average number of genotypes = 19, Table 1). Differences among treatment and non-treatment lakes could be affected by unequal sampling or the uneven distribution of genotypes (lower genotypic evenness) across waterbodies within each category, however, when we controlled for sample size, the pattern was consistent (Table 1) and may reflect strong selection for the most resistant genotypes in lakes that have been treated with herbicides. We also found that genetic variation was correlated with geographic distance such that more similar genotypes were observed in waterbodies closer in geographic proximity (IBD,r^2= 0.216, P> 0.01).

Table 1 Genetic Diversity– Genetic diversity indices of 10 populations of invasive watermilfoil across Michigan in A.) water bodies with histories of herbicide treatment, and B.) water bodies with no history of herbicide treatment. N = number of individual plants sampled per water body, G = number of genotypes identified per water body using the software GENOTYPE (Merimans & Van Tienderen 2004). Genetic diversity indices were calculated using the software GENODIVE (Merimans & Van Tienderen 2004) and included, G_e = effective number of genotypes (Lehman & Wayne 1991). Eve. = genotypic evenness. Nei's SS = Nei's genetic diversity corrected for sample size (Nei 1987). HSS = Shannon-Weiner diversity index corrected for sample size (Chao & Shen 2003).

A.	Herbicide	N	G	G_{Eff}	G_{Eve}	Nei's SS	HSS
1	Fine Lake	180	1	1.00	1.00	0.00	-0.00
2	Jordan Lake	85	5	1.16	0.23	0.14	0.20
3	Lake Geneva	150	3	1.03	0.34	0.03	0.06
4	Budd Lake	80	1	1.00	1.00	0.00	-0.00
5	Pike Bay	90	11	2.20	0.20	0.20	0.63
6	Torch Bay	90	3	1.06	0.35	0.06	0.09
	Mean		**4**	**1.24**	**0.52**	**0.07**	**0.16**
B.	Non-Herbicide	N	G	G_{Eff}	G_{Eve}	Nei's SS	HSS
7	Long Lake	167	4	1.05	0.26	0.05	0.08
8	Carter Lake	135	46	7.98	0.17	0.88	1.44
9	Lake Ovid	241	12	1.21	0.10	0.17	0.27
10	Silver Lake	144	14	1.41	0.10	0.29	0.45
	Mean		**19**	**2.91**	**0.16**	**0.35**	**0.56**

To examine patterns of genetic structure and admixture within the waterbodies, we employed Bayesian clustering methods implemented in the software STRUCTURE version 2.3.4 (Pritchard et al. 2000). Since this program assumes populations and their alleles are in a state of Hardy-Weinberg equilibrium, Bayesian clustering was performed on an individual water body basis so that Hardy-Weinberg assumptions were less likely to be violated. Furthermore, because flow cytometry and marker presence data both indicated that all watermilfoil plants sampled were hexaploid - likely allohexaploids - we first converted the multilocus marker data to a dominant marker format to overcome dosage issues which can complicate analysis. For each waterbody we completed a simulation analyses where we examined 20 runs of K=1 to K=10 to determine the K that best fits the data where "K" is the number of groups (assuming random mating) that

Table 2 Admixture– Admixture analysis for 10 populations of invasive watermilfoil across Michigan in A.) water bodies with histories of herbicide treatment, and B.) water bodies with no history of herbicide treatment. Admixed defined as individuals with Q values 0.01<Q<0.99.

A.	Herbicide	Mean Q	Admixed individuals	Percent admixed
1	Fine Lake	0.50	180	100%
2	Jordan Lake	0.49	85	100%
3	Lake Geneva	0.50	150	100%
4	Budd Lake	0.50	80	100%
5	Pike Bay	0.36	90	100%
6	Torch Bay	0.50	90	100%
B.	Non-herbicide	Mean Q	Admixed individuals	Percent admixed
7	Long Lake	0.02	2	1%
8	Carter Lake	0.37	50	37%
9	Lake Ovid	0.39	239	99%
10	Silver Lake	0.11	138	96%

describes the data. Post-hoc analyses of likelihood scores suggested that K=2 best describes the data for each lake except one lake in which K=3 was a better fit. To determine directionality of admixture we compared individual sample results to genotype information that we gathered for pure Northern and Eurasian watermilfoil genotypes. We found that admixture was more prevalent in populations from waterbodies with histories of herbicide treatment as individuals from all 6 treatment waterbodies have Q values between 0.01 and 0.99 and mean Q values approaching 0.50 (Figure 1, Table 2). However, the extent of admixture is difficult to determine because putative pure clusters of either Eurasian watermilfoil or Northern watermilfoil in our study might not actually be "pure" but highly advanced backcrossed hybrids. Since Q values only represent the probability of admixture and do not reflect the genetic contribution from parental species, individuals with Q values approximating 0 or 1 could still be the result of past hybridization events.

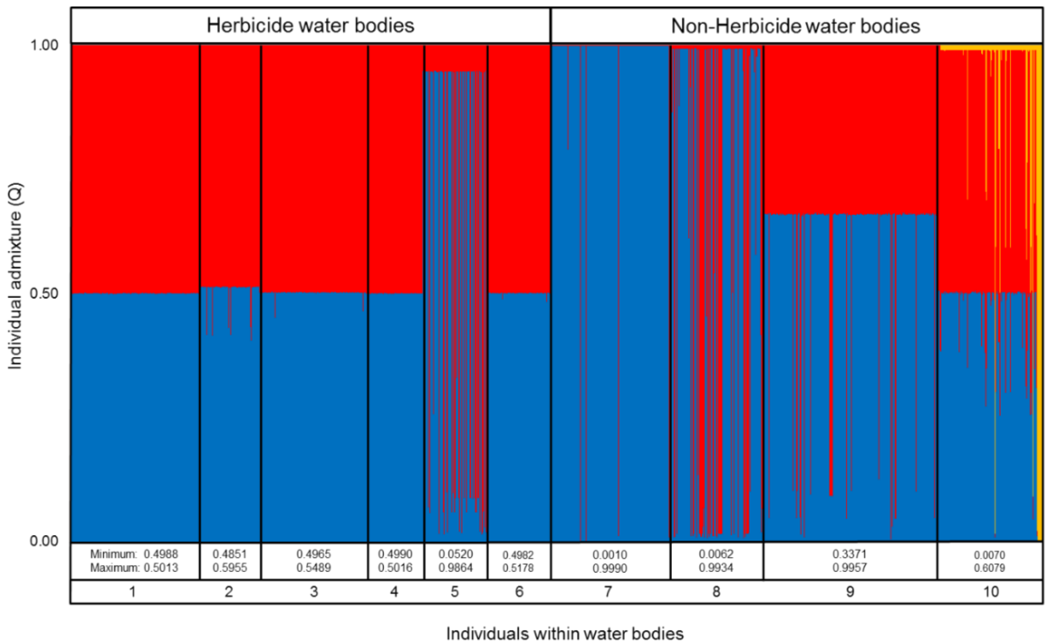

Figure 1 Structure Analysis of Genotype Groups - Admixture coefficient and optimal number of clusters based on rate of change in log likelihood of ΔK (Evanno et al. 2005) for all 1,362 sampled watermilfoil plants from 10 Michigan waterbodies run on an individual waterbody basis. Optimal number of clusters was K = 2 for each population with the exception of one lake which had an optimal number of clusters of K = 3. Numbers across x-axis represent individual water bodies (found in Table 1). A single vertical bar displays the membership coefficient of each individual. Blue represents the putative Eurasian watermilfoil (*M. spicatum*) cluster and red represents the putative Northern watermilfoil (*M. sibiricum*) cluster.

We also used principal component analysis (PCAs) to assess whether 8 abiotic environmental attributes (total dissolved nitrogen (TDN), total dissolved phosphorus (TDP) dissolved organic carbon (DOC), conductivity, temperature, pH, turbidity, and dissolved oxygen) and plant communities differed among a subset of herbicide treatment (4 waterbodies) and non-treatment water bodies (2 waterbodies). While the PCA for abiotic environmental variables showed no discernible patterns between herbicide treatment and non-herbicide waterbodies, the PCA for biotic plant community showed stark differences between herbicide treatment and non-herbicide waterbodies across principal component axis 1 (Figure 2). Plant species that cluster towards herbicide treatment waterbodies (n = 11) across the first principal component axis are comprised entirely of monocot species with the exception of Eurasian watermilfoil (dicot) and aquatic moss (*Drepanocladus* sp.), a non-vascular plant. Plant species that cluster towards non-herbicide waterbodies across principal component axis 1 (n = 19) include a variety of monocot and dicot plants. The cause and effect of this pattern in not known.

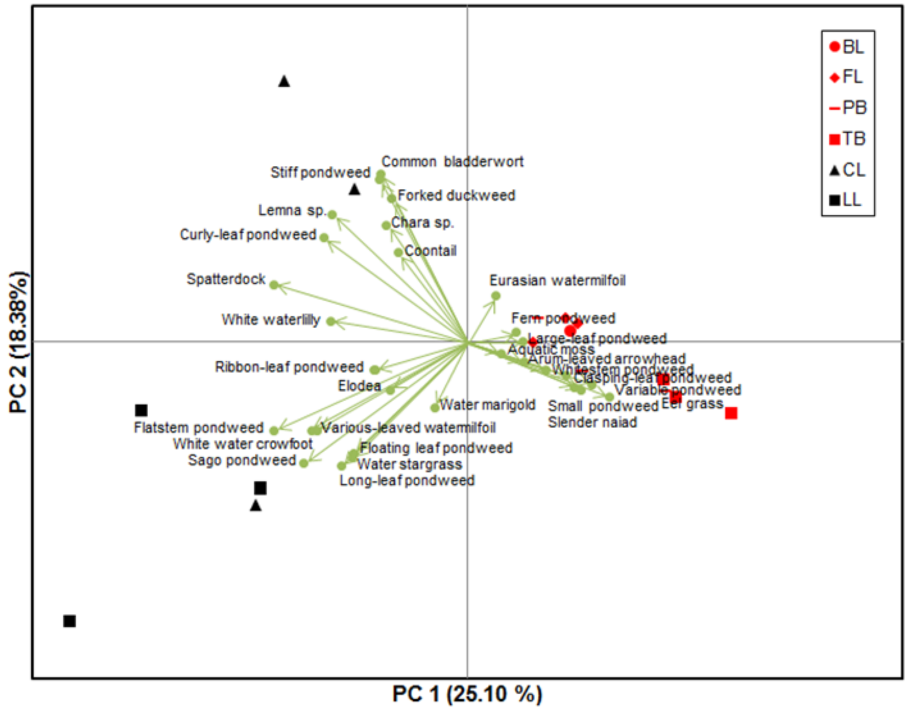

Figure 2 Principal component analysis (PCA) of biotic plant communities per site. Red symbols represent waterbody sites with histories of herbicide treatment and black symbols represent sites with no history of herbicide treatment. Green arrows represent the corresponding eigenvectors for PC 1 and PC 2 for biotic plant communities.

Sensitivity Analysis: As detailed in previous reports, we surveyed and collected plant samples from water bodies that records indicate had either been treated at least once within the last five years with herbicides that target invasive milfoil ("herbicide treatment lakes," n = 7) or that have not previously been treated with herbicides within the last five years ("non-herbicide treatment lakes," n = 4). Healthy plant fragments were sent to SePRO Corp. (Carmel, IN) and subjected to one of three herbicides (2,4-D, Triclopyr, and Fluridone) in a PlanTEST bioassay in order to determine herbicide susceptibility. Overall results indicate that the great majority of watermilfoil individuals exhibited relatively high sensitivity to the three herbicides.

Statistical analyses of the effect of genotype class on susceptibility to different herbicides was limited by both low number of genotype classes (>95 percent were identified as pure EWM or as highly advanced backcross hybrids to EWM) and that most individuals in susceptibility testing were identified as susceptible. To account for such low power we analyzed the data using nominal logistic regression with susceptibility as the dependent variable and treatment (control, treated) and genotype class (EWM, NWM, F1, F2, or backcrosses to EWM or NWM) as fixed effect independent variables (low power prevented examination of interaction between independent variables). We found that treatment history of the lake ($X^2 = 9.08$, $P = 0.0026$; $X^2 = 5.63$, $P = 0.0176$) but not genotype class ($X^2 = 4.31$, $P = 0.1157$; $X^2 = 3.14$, $P = 0.8549$) had a significant influence on sensitivity to both 2,4, - D and Triclopyr. In general, individuals from treatment lakes were less susceptible to both 2,4, - D and Triclopyr. In contrast, we found that neither treatment history ($X^2 = 1.99$, $P = 0.1579$) nor genotype class ($X^2 = 0.35$, $P = 0.8381$) had a significant influence on susceptibility to fluridone. Nearly all individuals showed sensitivity to fluridone. The specifics of the interpretation of the PlanTest results remain to be approved of by SePRO prior to dissemination.

Objective 3 – Alternative control measures and community associations.

- **Alternative Control measures:** As documented in our previous reports, we worked with personnel from Many Waters, LLC to plan and conduct the deployment of an experiment to assess the efficacy of Diver Assisted Suction Harvesting (DASH) as a control measure for

Eurasian Watermilfoil. With the necessary DNR/DEQ and Army Corps permits, we conducted experimental DASH removal of invasive milfoil in waters of Pike Bay of the Keweenaw Waterway, Chassell Township in July 2017. The experimental design included 5 pairs of 3m*5m quadrats (paired control and Eurasian Watermilfoil removal plots) at a site in the Keweenaw Waterway where abundant Eurasian Watermilfoil was detected. We conducted pre-DASH and post-dash surveys of aquatic macrophytes, macroinvertebrates, and unmanned aerial system (UAS or "drone") based remote assessments of the sites using spectral and visual light imagery (see objective 4).

Macrophytes communities of study plots were species rich (average 11 species) with species in the highest abundances in order being: *Elodea canadensis*, invasive watermilfoil (IWM), V*allisneria americana, Chara* spp., and *Bidens beckii*. Total macrophyte biomass densities before DASH were similar between paired control (23.7 ± 2.8 $g*m^{-2)}$ and DASH assigned plots (21.0 ± 4.2 $g*m^{-2}$). Plots also had similar densities of IWM in paired control (8.2 ± 1.8 $g*m^{-2}$) and DASH plots (6.7 ± 2.5 $g*m^{-2}$). One month after DASH treatments, total macrophyte biomass increased for all plots about 2-fold for control (paired t-test, p=0.05, t=2.2, df=4) and DASH plots (paired t-test, p=0.09, t=1.6, df=4). IWM in the control plot increased approximately 3-fold (22.5 ± 8.5 $g*m^{-2}$) while IWM biomass in the DASH plots remained lower than pre-DASH biomasses (3.7 ± 3.3 $g*m^{-2}$) but not significantly different (paired t-test, p=0.48, t=-0.8, df=4). Prior to DASH underwater light readings of photosynthetic active radiation (PAR) at 1-1.1m depth were not significantly different between paired and control and DASH plots (paired t-test, p=0.24, t=-1.4, df=4). One month after DASH, DASH plots had significantly higher PAR readings (paired t-test, p=0.02, t=2.8, df=4). If light was limiting, this increase in light availability would be predicted to reduce competition for light for native macrophytes. Aquatic macroinvertebrates have all been identified generally to family and we are currently analyzing the resultant data. Follow-up sampling of macrophytes and macroinvertebrates within the plots was conducted on Aug 29, 2018 (see Problems Encountered, Objective 3)

Objective 4 – Enhance detection of Invasive watermilfoil via remote sensing

- **IWM mapping:** Early in this project, a spectral-based classification method was developed using a 2012 multispectral commercial satellite image of the Les Cheneaux Islands archipelago in northwestern Lake Huron. Invasive milfoil growth reached epidemic proportions in summer 2012 in Les Cheneaux, making it a useful case study for classification method development also applicable to inland lakes. The final classification (Figure 3) includes four spectrally separable submerged aquatic vegetation (SAV) classes as well as a deep-water/dark SAV class, a sparse SAV class, and a floating aquatic vegetation class. Based on field and aerial photos and qualitative information on vegetation growth and distribution in 2012 provided by the Les Cheneaux Watershed Council, it is likely that the class 'SAV 2' represents a dense monoculture of IWM, 'SAV 1' represents a mixture of lower-density IWM and other SAV species, 'SAV 4' represents mixed SAV and floating-leafed vegetation with an IWM component, and 'SAV 3' primarily represents benthic algae. This map demonstrates that satellite imagery can be used for initial mapping of surface aquatic vegetation vs. submerged aquatic vegetation even in the absence of field data.

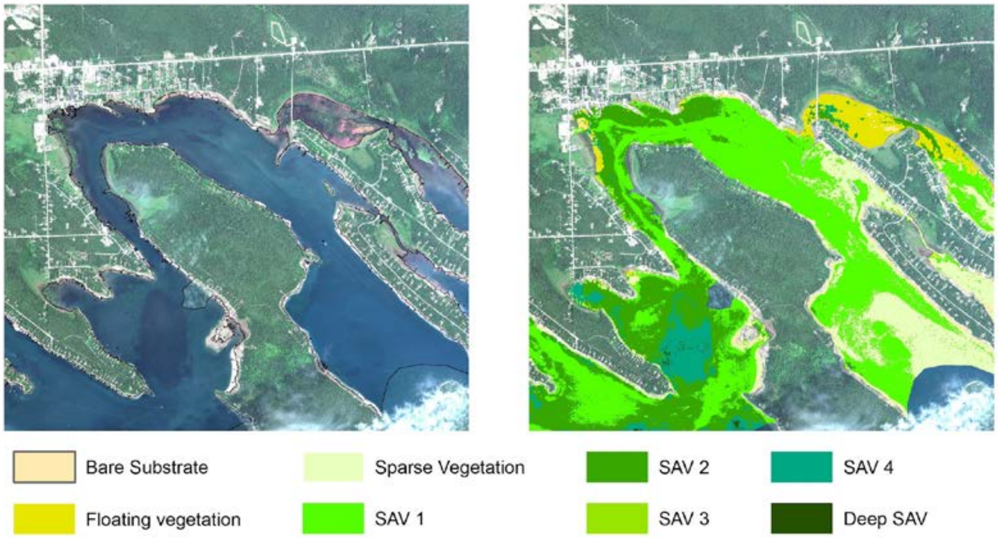

Figure 3. Classified aquatic vegetation map of Cedarville Bay in the Les Cheneaux archipelago, summer 2012.

More recently, this map was updated using similar imagery collected in summer 2016, when IWM was much less prevalent (Figure 4), informed by point-intercept field data collected by the local Les Cheneaux Watershed Council in August 2016. An accuracy assessment of this map, performed using a subsample of this field data, indicated an overall map accuracy of 87.4% (Table 3). The performance of this approach demonstrates that spectral-based unsupervised classification tuned with field data can be an effective technique for mapping IWM.

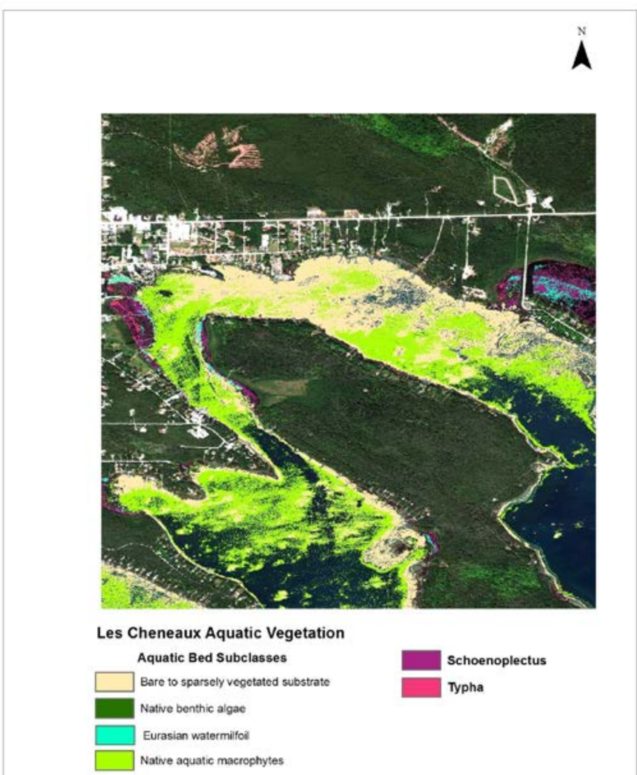

Figure 4. Classified map of 2016 aquatic vegetation cover in Cedarville Bay, Les Cheneaux Islands.

Table 3. Error matrix for the classified map shown in Figure X, based on coincident field truth data.

	Bare	Schoenoplectus	Algae	EWM	SAV (non-EWM)	Typha	ACTUAL	PRODUCER'S ACCURACY
Bare	5	0	0	0	0	0	5	100.0%
Schoenoplectus	2	1	0	1	0	0	4	25.0%
Algae	8	0	25	0	0	0	33	75.8%
EWM	0	0	0	3	0	0	3	100.0%
SAV (non-EWM)	0	0	0	0	38	0	38	100.0%
Typha	0	0	0	0	0	4	4	100.0%
PREDICTED	15	1	25	4	38	4		
USER'S ACCURACY	33.3%	100.0%	100.0%	75.0%	100.0%	100.0%		
TOTAL ACCURACY		87.4%						

For more detailed mapping, especially of small and mixed IWM patches, higher-resolution data are really needed. Figure 5 provides an example of using an Unmanned Aerial System (UAS) to take high-resolution aerial photos of the transects in one of the inland study lakes (Carter Lake), which were then mosaiced and classified. Similar maps were also generated for the Fine Lake and Long Lake study areas. These maps provide sufficient detail for helping to locate areas of EWM within lakes.

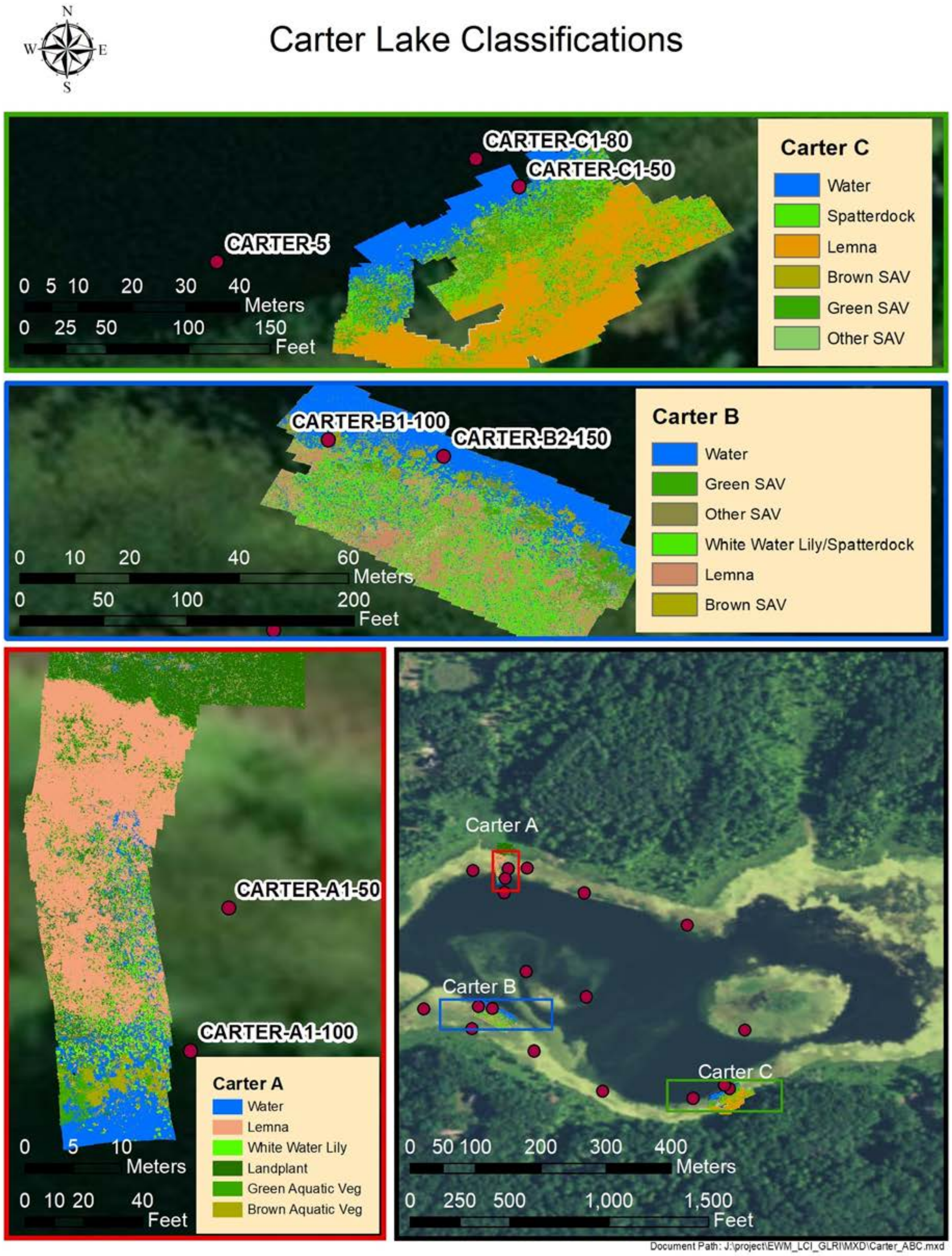

Figure 5. Classified UAS imagery of transects A, B, and C in Carter Lake.

UAS imagery was also valuable in the course of this project for documenting the impacts of the DASH experiment in 2017 (Figure 6). High-resolution imagery of the experiment area collected with a near-infrared (NIR) camera mounted on a UAS before and just after the DASH activity clearly showed the effect of DASH on the aquatic vegetation biomass. The NIR imagery helps highlight areas of remaining IWM vs. the areas removed with DASH more clearly than traditional natural color imagery (Figure 7).

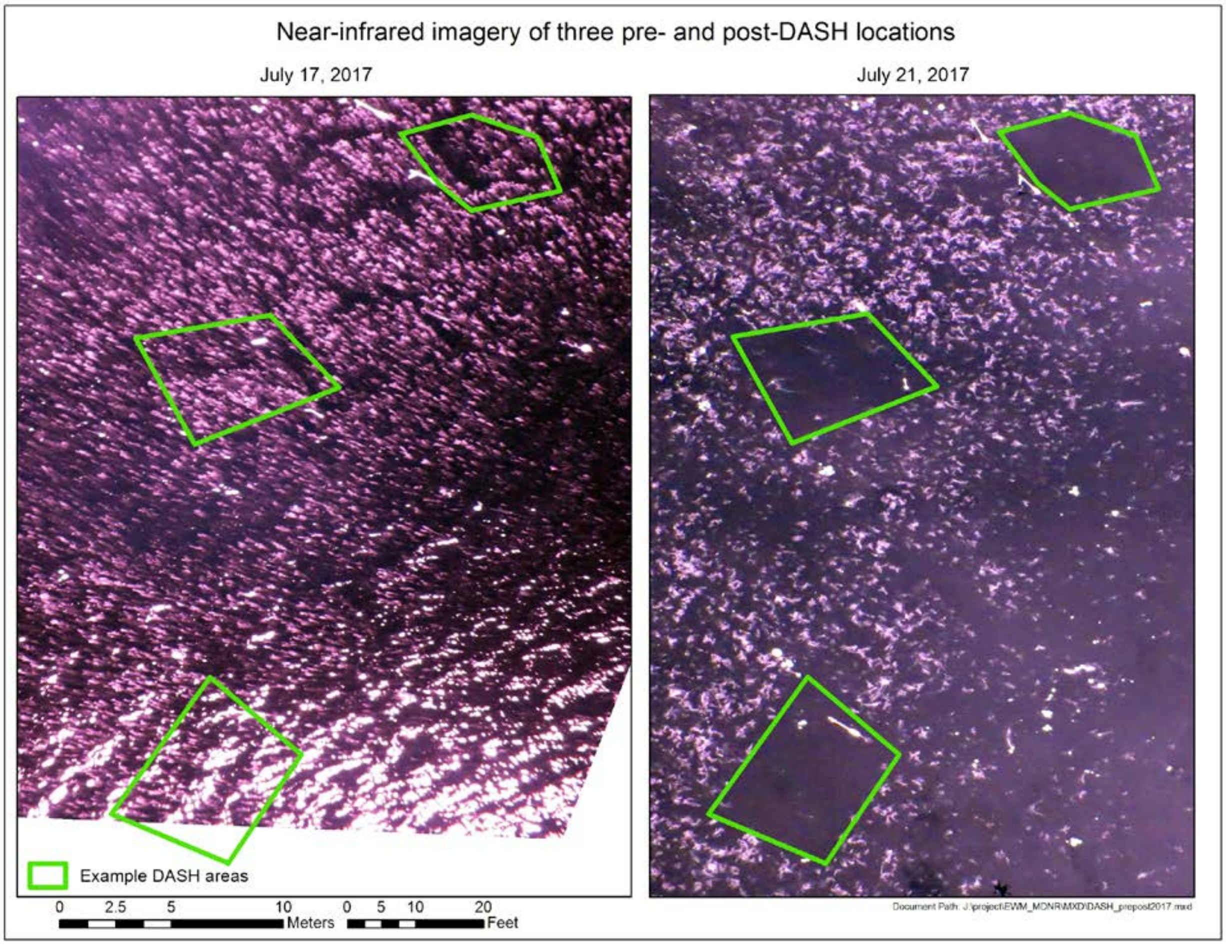

Figure 6. Near-infrared imagery collected in Pike Bay before and after the DASH removal of IWM in July 2017. Brighter areas in the image represent vegetation growing close to the surface; vegetation is highly reflective at near-IR wavelengths.

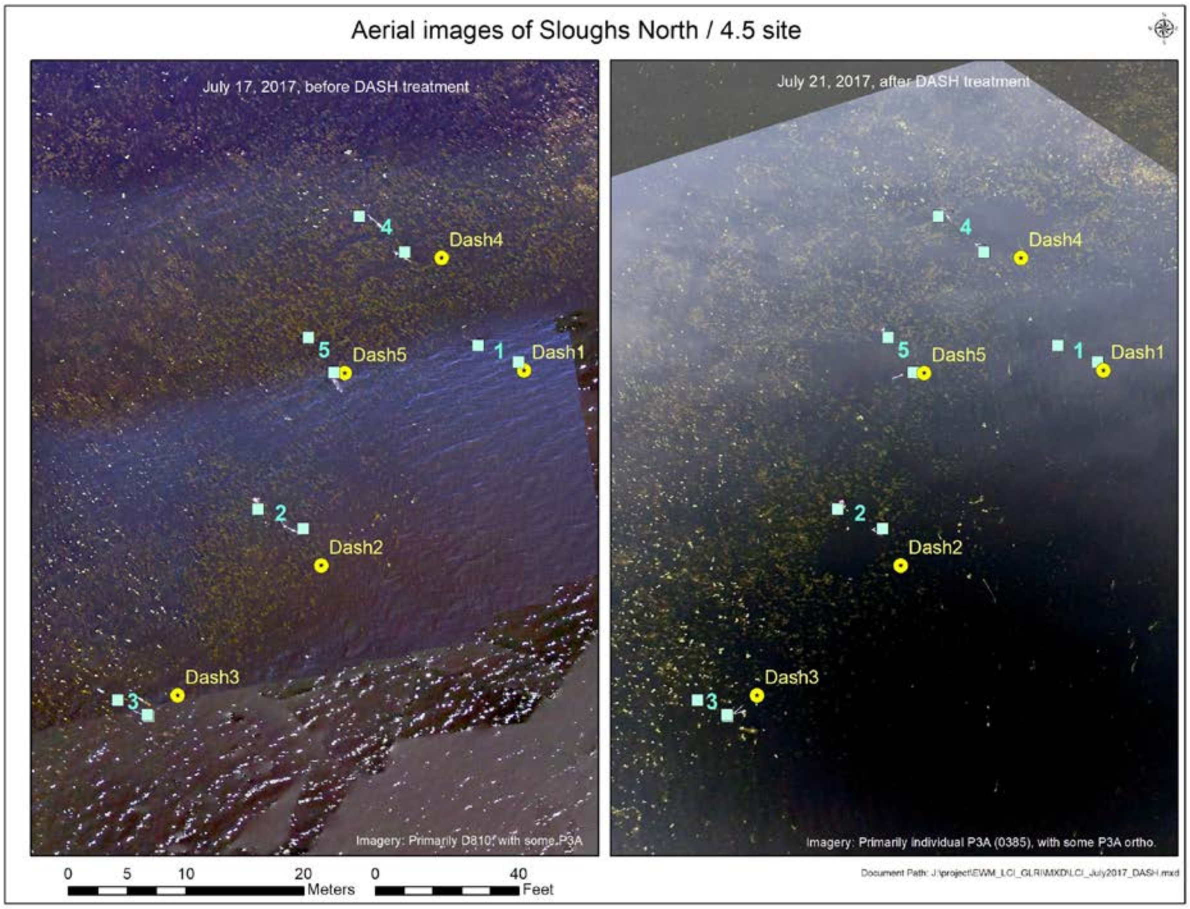

Figure 7: Natural color imagery taken with UAS of the DASH areas immediately before and after DASH treatment, showing GPS locations of the five DASH treatment areas. While the reduction in IWM is visible, it is more clear in the NIR imagery also flown at these times.

- **Spread modeling:** To support the overall goals of this project, existing and remote-sensing-derived datasets on lake physical and environmental conditions, along with proxies for Invasive Watermilfoil (IWM) propagule pressure and EWM observation data, for 778 lakes (153 known EWM-invaded and 625 background/unknown status) in central southern Michigan were used to model the lake characteristics suitable for invasive watermilfoil (IWM) establishment. The performance of principal component analysis (PCA) and a Gaussian process species distribution model were used to characterize the range of habitats suitable for the survival of IWM and the factors that may regulate its spread.

  Two variables were selected as important by both the PCA and the GP model: distance to nearest known infestation and presence of a public boat launch. Both of these variables relate to propagule pressure rather than the biotic or abiotic lake characteristics. This could reflect IWM's tolerance of a broad range of environmental conditions. Alternatively, it may be that the environmental covariates did not capture the factors driving IWM establishment. The covariates extracted from satellite data (trophic state index, lake surface temperature, watershed land uses) were not shown to be important predictors for this dataset.

  Maximum depth is a potentially important input variable not included due to lack of availability. Some set of water chemistry variables (pH, alkalinity, conductivity, nutrients) are probably important to IM establishment, but collecting these data for every inland lake for a regional-scale model is cost-prohibitive. Nutrient status is reflected to a certain extent by the Landsat-derived trophic state index. There is no publicly available database of private boat launches in Michigan inland lakes, so these are not accounted for in the lake accessibility sub-model. It is reasonable to assume that private boat ramps are much less active than public ramps, reducing the importance of this missing variable.

Objective 5 – Outreach and education.

- **Presentation at Professional Meetings/events:**

  Brooks, C., Marcarelli, A., Grimm, A., Dobson, R., Huckins, C., Van Goethem, R., Smith, R., Clymer, M. "Analyzing Eurasian Watermilfoil Extent and Treatment Efficacy using Unmanned Aerial System (UAS) Multispectral Imagery". Society for Freshwater Science Conference, Detroit, MI (May 2018).

  Brooks, C., Marcarelli, A., Grimm, A., Dobson, R., Huckins, C., Van Goethem, R., Smith, R., Clymer, M. "Demonstrating Unmanned Aerial System Multispectral Analysis of Eurasian Watermilfoil Treaments". International Association for Great Lakes Research Annual Conference, Scarborough, Ontario (June 2018).

  Van Goethem, R., Marcarelli, A.M., Huckins, C.J. "Effects of invasive macrophytes on littoral primary producers in north-temperate lakes." Midwest Aquatic Plant Management Society 38th Annual Meeting, Cleveland, OH. (March 2018).

  Van Goethem, R., Marcarelli, A.M., Huckins, C.J. "Effects of invasive macrophytes on littoral primary producers in north-temperate lakes." Society for Freshwater Science Annual Meeting, Detroit, MI (May 2018).

  In total members of this project team have made 20 presentations at professional meetings where results from this project were shared.

- **Publications:**

  This project has thus far resulted in three MS theses (two defended and one scheduled) at Michigan Technological University. One manuscript currently in review was partially supported by activities resulting from this project.

- **Outreach:**

  Since the last reporting period we have conducted two additional outreach events in the summer of 2018:

  1) 18 under-represented high school students from throughout Michigan participated in a kayaking field trip jointly led by Joan Chadde, Director of the MTU Center for Science & Environmental Outreach, and the MTU Outdoor Adventure Program, to identify Eurasian milfoil and other invasive species at Sturgeon River Sloughs in Chassell, MI.

  2) 18 under-represented high school students from throughout Michigan participated in a field trip jointly led by Dr. Sigrid Resh, Director of the Keweenaw Invasive Species Management Area (KISMA), to identify Japanese Knotweed and other invasive species and discuss management and control options.

2. Problems encountered during the grant period: [List N/A if no problem exists.

Objective 1 - Retrospective Analysis:

- Through conversations with DEQ ANC we have recently determined that treatment report data prior to 2007 is not available, which will limit the possible analysis to treatments occurring beginning with 2007. As outlined above while we now have the raw data for years 2007-2015, a major task remains to render this data usable. The permitting history for each water body needed for this analysis is contained on individual treatment permits. In our initial attempts to work through those data sets and link survey data and permit history for a given waterbody, we were unable to make this linkage because the identifying codes for waterbodies and those for the permit applications were different. This required requesting and receiving an additional data set (permit list) that includes an identifying code that crosslinks the survey data with permit data. It is yet unclear to us if it is feasible to complete the analysis goal as originally planned as the permit history information (waterbody, herbicide, treatment date) will have to be extracted one at a time from the treatment reports (often hand written) for each waterbody and year, and the copies of the permits we have are scans of the permits (groups of 25 for some years), and distributed in over 6500 files (e.g., see attached: Example Treatment Reports.pdf). An additional issue is the difficulty of identifying a before and after herbicide period for a given lake. Based on review of the herbicide application permits, lakes that have some herbicide application tend to have a long history of treatment, and it is unclear whether pre-treatment data exists given the lack of data prior to 2007. We will work with DEQ to assess the feasibility of conducting meaningful analysis of their large dataset.

Objective 2 – Milfoil genotype diversity and patterns of hybridization in relation to herbicide sensitivity.

- Due to initial low microsatellite sequence variation, we decided to include more samples per lake to try and detect additional nuclear polymorphism rather than focus on chloroplast sequence variation as originally proposed. However, after completing microsatellite analyses of nuclear variation for all samples, we still did not uncover much variation. Ultimately, we decided to focus our remaining time and resources on examining chloroplast variation to try to ascertain maternal lineages. We amplified and sequenced two chloroplast regions (TrnL/F and RPL32-TrnL) from a total of 27 individuals that had unique genotypes as determined via the microsatellite analyses (26 invasive watermilfoil and native Northern watermilfoil individuals). Initial inspection of these sequences shows that there is also minimal variation among genotypes in chloroplast sequence variation. We are in the process of analyzing the chloroplast data to determine haplotype representation.

Objective 3 – Alternative control measures and community associations.

- **Native Plant Mats for Rehabilitation:** We explored the efficacy of developing mats of native plants using choir matting as the base with the goal of deploying them to replant a treatment area with native species. Although this approach has worked in other systems (e.g., sea grass restoration) we were unable to develop mats of sufficient integrity and plant density to be useful. We do believe that if they could be developed this would be a useful approach to rehabilitating areas or controlling invasive growth in small areas such as around boat docks while still providing important macrophyte habitat for lake ecosystems.

- **DASH Experiment:** In our original plan we proposed to conduct DASH in conjunction with herbicide treatments to assess the value of multiple approaches to treatment. In extensive consultation with ManyWaters who were contracted to conduct the DASH treatments we discussed the potential safety hazards they may be encounter from prolonged exposure to the proposed mixture of herbicides used in the permitted study system of Chassell Bay of the Keweenaw Waterway, Michigan. The determination of undue safety hazard, which we all agreed on, meant we needed to move the DASH treatments to other waters within our permitted waters. Available sites with sufficient Eurasian Watermilfoil abundances for treatment limited the scale of the experimental DASH removals we could conduct. Rather than conducting a larger area of DASH in the region we determined to do 5 paired plots within the invaded sites to allow for statistical analysis of the results.

  We conducted pre-and post-DASH surveys in 2017 as outlined above; however, the timing of our annual follow-up sampling for the DASH experiment was limited by water contact advisories from the Western U.P. Health Department due to high levels of harmful bacteria following the 1000-year rain fall and subsequent high flows during the Father's Day floods on June 17 (Detroit Free Press 18 Jun 2018 story - https://www.freep.com/story/news/local/michigan/2018/06/18/upper-peninsula-flooding/709406002/; MPR story on flood size 28 Jun 2018 - http://www.michiganradio.org/post/record-breaking-rain-behind-floods-something-we-can-expect-more). This storm event caused sewer overflows and erosion which affected all of Portage Lake initially and were extended in some locations following additional storms on July 12. Most beaches in Portage Lake were reopened for recreation by July 26, by which time vegetation had regrown on the DASH plots to such a level that it has been difficult to locate our underwater markers to conduct repeat sampling.

Objective 4 – Enhance detection of Invasive watermilfoil via remote sensing

- In some cases, it proved challenging to match the field survey points to the vegetation types being seen in the UAV imagery for the inland lakes. To identify plant species, a precise knowledge of what plant species are present is really needed at the scale of individual plants over distances of less than 1m. To address this, subsequent SAV mapping work successfully used temporary buoy markers that can be seen in the UAV imagery, with vegetation surveys taking place immediately around the marker buoy.

Objective 5 – Outreach and education.

N/A

3. **Remedies of the problem(s) indicated in item 2 and how they may be avoided in the future.**
Remedies to problems we encountered during the course of this project have been described above or they are presented in the description of post-completion activities below.

4. **Rate of expenditure versus progress on project.**
Grant expenditures are in line with progress and we encountered no budgetary issues within this project. The project budget was originally planned to be expended over two years with relatively similar expenditures in each year (2015-2016, 2016-2017). We requested and were granted a one-year no-cost extension until June 30, 2018. The majority of funds (58.5%) were expended in the final period (June 2016 - June 2018), which included the extension.

5. **Equipment purchased during the reporting period**
N/A No equipment (value >$5,000) has been purchased for this project.

6. **Steps taken to limit spread of invasive species.**
We have conducted no activities since the last reporting period that could have spread invasives. In our previous activities involving sampling of multiple lakes in the lower peninsula of Michigan where access to boat wash stations was limited, we would power wash all buckets, sampling gear, the boat, and trailer at car wash stations.

Post-completion activities that will be the responsibility of the GRANTEE.

- ***Retrospective Analysis***: We will work with the DEQ to examine the survey data to attempt to learn of possible associations between macrophyte composition and herbicide application history of Michigan lakes in their database.
- ***Vegetation Assessment and Water Chemistry***: We will continue to work on processing various samples for water chemistry for general sampling and DASH experiment.
- ***Database:*** The database has been constructed and we are in the process of importing data, which will continue into the future of this and related projects.
- ***Genetic Analysis***: We will continue analysis of Chloroplast DNA fragments in order to better determine maternal kinship of individuals. This will help to better determine the hybridization dynamics and infer maternal lineages of the samples.
- ***Alternative control measures and community associations:*** We will continue to sample the macrophyte and macroinvertebrates within the control and the DASH removal sites to assess the longer term effects of the manual removal of Eurasian Watermilfoil.
- ***Risk Modeling and Remote Sensing***: The grant objectives for this task are complete.
- ***Outreach***: We will work with our local Townships to hold an outreach event at which we present the final results of our Eurasian Watermilfoil research and control project to local township residents.

Describe any plans for continuing activities funded under this grant in the future.

N/A

Final Report Checklist

Review the following checklist of required documents for the grant program, noting which files need to be submitted with the final report and which must be kept on file for audit.

Required Documents	Submit	Keep in File
Progress Report Template	X	
Progress Report Tracking Workbook.xls	X	
5-10 Publishable Photos	X	
Outreach materials, including press releases, maps, or web links, etc.	X	
Meeting, Training, or Event sign-in sheets		X
Landowner Agreements		X
Permits		X
Survey and Treatment records		X
Survey and Treatment records		X

Financial Status Report:

Include an itemized list of all the expenditures and donations made during the entire project period and a list of the payments (advances and reimbursements) received by the GRANTEE.

Final Reimbursement Request:

Include a final reimbursement request with a tabulation of the total project costs and documentation of expenditures not already submitted to the DEPARTMENT.

GRANTEE Statement of Project Completion

Statement	Signature of GRANTEE
All relevant data uploaded to MISIN	
All other required documents attached or located in project file	
Project completed in accordance with the DEPARTMENT-approved Budget and Work Plan	

DEPARTMENT Statement of Project Completion

Statement	Signature of DEPARTMENT representative(s)
I have received and approved the GRANTEE's Final Report Documents, including the Final Performance Report, Financial Status Report, and Final Reimbursement Request. I certify that the project has been completed within the project period and as described in the executed grant agreement (including any amendments executed between the DNR and the grantee).	*Technical: Signature, Division, Department (Final Report)* *Date* *Grants Management (Financial Status/Final Reimbursement)* *Date*

Les Cheneaux Islands Eurasian Watermilfoil Control

Final Report

US Environmental Protection Agency (EPA) Great Lakes Restoration Initiative Project
Grant No. GL-00E01928-0

Period of Performance: March 31, 2016 to September 30, 2018

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Project Collaborators:
Les Cheneaux Watershed Council: Robert Smith, Mark Clymer, Scott Myers

December 29, 2018

1. Table of Contents

2. Executive Summary

This 30-month project, a collaboration between Michigan Technological University and the Les Cheneaux Watershed Council, consisted of deploying a fungal plant pathogen indigenous to the Great Lakes, *Mycoleptodiscus terrestris* (Mt), that reduced the biomass and growth of invasive Eurasian watermilfoil (*Myriophyllum spicatum,* or EWM) in the Les Cheneaux Islands (LCI). Detailed field methods documented densities and biomass of EWM and other submerged aquatic vegetation at sampling sites. The use of multi-scale remote sensing methods, from satellite imagery to unmanned aerial systems (UAS), were demonstrated and documented to be useful to mapping EWM extent and monitoring multiple treatment methods, including the Mt application plus mechanical harvesting and diver-assisted suction harvesting (DASH). While permitting requirements meant that Mt fungus could only be applied on areas totalling one acre, UAS-enabled mapping of EWM was demonstrated for six areas, and satellite-based mapping was completed for an area of over 1730 acres in the LCI.

The project was organized into an approach comprised of five task areas, as described in the selected proposal, with the following major outcomes:

Approach Area 1: Planning and Permitting established that all biocontrol applications, mechanical harvesting and dredging aimed at EWM control was performed with appropriate permits, and that field and UAS surveys were planned and approved in advance to ensure that the project goals would be met. This included the creation and approval of a Quality Assurance Project Plan, approved on September 12, 2016, which was revised in December 2017 to reflect project changes. These changes included 1) the application of Mt under a USDA APHIS permit rather than an EPA Experimental Use Permit, 2) a change in the source of Mt from the USDA Agricultural Research Service to Wisconsin BioProducts, and 3) additional work to leverage a related project by using UAS imaging to evaluate the the effectiveness of Diver-Assisted Suction Harvesting (DASH) for controlling EWM in the Keweenaw Waterway. These changes were approved by EPA on December 21, 2017.

Approach Area 2: Treatment built on previous research and testing of Mt formulations for EWM control in the Les Cheneaux Islands and elsewhere to ferment a liquid culture of microsclerotia of the USDA TX-05 strain of Mt fungus. Whole-culture Mt was diluted with local lake water and applied via gravity feed from a mixing tank. The application protocol was based on the best information available from previous trials and lab work. The results of the 2017 pilot application of a liquid Mt culture will inform and improve future use of Mt for EWM biocontrol, which have been documented in an updated list of best management practices for use of Mt. Mechanical harvesting of EWM was also demonstrated to be complementary to biocontrol in areas where Mt application would be difficult or unwanted.

Approach Area 3: Monitoring, which was divided into two areas:
3a. Remote sensing-based monitoring and mapping
Multiscale remote sensing-based mapping included peak growth (2012) and recent (2016) maps of aquatic vegetation cover across a large swath of the Les Cheneaux waterways (1730 acres),

while finer-scale maps derived from UAS imagery allowed for more detailed monitoring of treatment response across multiple sites in the Les Cheneaux Islands in 2016, 2017 and 2018 (see Figures 11-19 below for examples from six locations in the LCI).

3b. Field surveys, including collecting ecological and macrophyte community data
An integrated field assessment included surveys of aquatic macrophyte abundance, species composition and biomass, surveys for milfoil weevils, and water quality measurements (dissolved organic carbon (DOC) concentration and composition, water clarity, conductivity, pH, and water chemistry) to better understand treatment response and to serve as field truth for algorithm development for classifying the satellite and UAS imagery.

Approach Area 4: Development/improvement of Mt biocontrol methods
The GLRI "Arresting the spread of Eurasian watermilfoil in Lake Superior" grant started a centralized, web-based clearinghouse of reliable information on EWM control and management. This information is available at http://www.mtri.org/eurasian_watermilfoil.html and includes information on biology, invasive properties and ecological impacts, development of mapping and modeling tools, spread, and further web resources. This leveraging of previous work and extending it through work took advantage of this project taking place in Les Cheneaux Islands, where an active community represented by the Les Cheneaux Watershed Council has been working to implement effective, safe, and economical biocontrol programs. LCWC has been posting information on its Mt biocontrol work to serve as information for updated best management practices for use of this treatment method. For examples, please see http://lescheneauxwatershed.org/projects/mycoleptodiscus-terrestris and especially their final report at http://www.lescheneauxwatershed.org/library/nuisance-species/eurasian-watermilfoil/lcwc-ewm-research/310-wc6-use-of-mycoleptodiscus-terrestris-as-a-mycoherbicide-for-myriophyllum-spicatum-eurasian-watermilfoil-management-in-the-open-water-system-of-the-les-cheneaux-islands-michigan (Smith et al. 2018a). The LCWC final report serves as a detailed description of the Mt treatment methods and impacts, and are described in further detail below in Section 4.

Approach Area 5: Reporting and Communication of Results
The project has included an active outreach program focused on communicating results to both local stakeholders and the scientific community. This has included sharing results with the Les Cheneaux Watershed Council in person and through their newsletter, sharing information at the FrogFest annual community festival, giving presentations at the Les Cheneaux Community Library and to science students at Cedarville High School, and presenting at scientific meetings including International Association of Great Lakes Research (IAGLR) Annual Conferences, the Society for Freshwater Science Conference, and the Ecological Society of America (ESA) conference. In addition, the EWM resource page from the project team's previous "Arresting the spread…" GLRI project focused on EWM was updated, a dedicated project web page was created and maintained at http://www.mtri.org/ewmlci.html, educational signage was posted at treatment sites, and the Great Lakes Echo reported on the project ("Fighting invaders with drones and fungi" - http://greatlakesecho.org/2016/09/30/fighting-invaders-with-drones-and-fungi/).

Sharing invasive species biocontrol knowledge, experience and methods is critically important for others in the biological control community to understand what is working and what is not. Case studies of relatively new biocontrol vectors in field conditions can be especially useful. By applying Mt at a pilot scale in a Great Lake coastal zone, updating the available information on EWM biocontrol information, demonstrating a detailed EWM monitoring field protocol, and applying remote sensing tools, this project has contributed to the development of an integrated EWM management strategy that includes flexible options for sites where herbicide application is inadvisable or unwanted.

3. Project Overview/Background

Since the mid-2000s, several inland lakes and sheltered Great Lakes bays in and along Michigan's Upper Peninsula have developed populations of the aquatic invasive species Eurasian watermilfoil (*Myriophyllum spicatum*, or EWM). This invader has been especially prolific in the Les Cheneaux Islands (LCI, Figure 1), where as early as 2003, a Michigan Department of Environmental Quality (MDEQ) survey of Cedarville Bay found that EWM had colonized 225 of 289 surveyed acres. Point intercept surveys of Cedarville and Sheppard Bays found EWM present at 46% of survey points in 2014 (approx. 350 acres) and 18% in 2015 (approx. 135 acres). In the peak EWM growth years of 2006 and 2012, local fish catches declined notably, and boaters were unable to navigate nearshore waters without the weed fouling their propellers. EWM has continued to be a problem in the years since, with visible infestations during summer surveys in the docks and other high-traffic areas in the main local communities of Cedarville and Hessel.

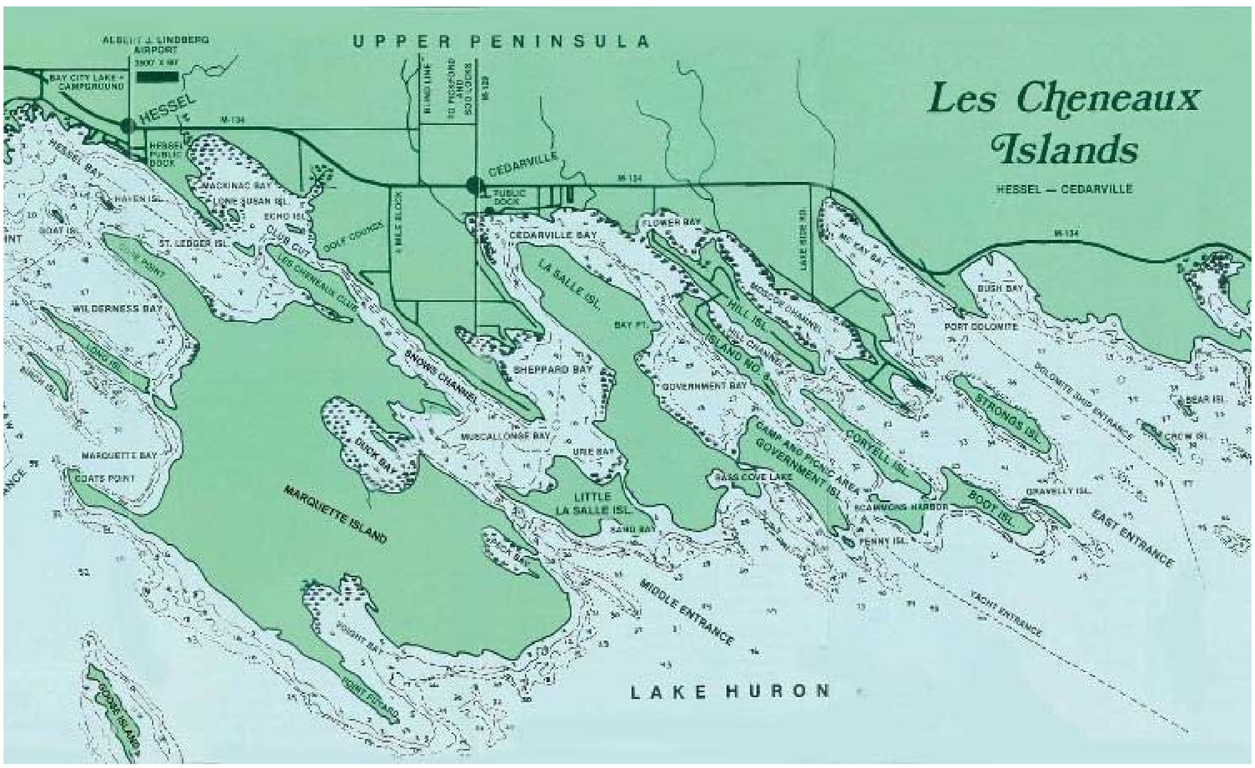


Figure 1: Map of the Les Cheneaux Islands, with circles showing the main study locations of the towns of Hessel (left top) and Cedarville (center near top).

The 36-island LCI archipelago includes almost 200 miles of Great Lakes shoreline and shelters an intricate complex of shallow bays and channels that represents important aquatic habitat, particularly for fish species. The north shore of Lake Huron, including the LCI, was identified in *State of the Great Lakes 1999* as “a significant biodiversity investment area”. The islands’ recreational opportunities make the area popular for tourists, anglers, boaters, and homeowners, including over 4,000 seasonal and full-time residents in Clark Township, which includes Cedarville and Hessel. Small communities such as these along northern Great Lakes shorelines rely on the nearshore waterways, ecosystems, and fish and bird habitat that enable the region's tourism industry. Left unmanaged, EWM can severely impact both the ecosystems and financial viability of local communities. Dense surface weed canopies can suppress desirable native plants, indirectly impacting fish and other aquatic organisms that are important for local tribal subsistence fishing and commerce as well as recreation and tourism. For these reasons, the 2012-2017 Michigan Tourism Strategic Plan identified invasive species as a primary threat to tourism in the State of Michigan (Nicholls 2012). EWM growth also directly impacts property values; in the LCI, 34% of waterfront properties have been adversely affected by dense EWM growth, and the estimated taxable value of twenty percent of township properties has been reduced due to degraded aesthetic values (total taxable value of EWM-impacted properties was reduced to 25% of that of similar, non-impacted properties; estimates from Clark Township Supervisor in 2015).

Responding to the local community's strong preference for avoiding commercial herbicide use at the scale that would be required to control the area's nuisance EWM (and the approx. 120 potable water intakes currently used by area residents, which present an obstacle to chemical herbicide application), and building on previous work testing and developing EWM biocontrol methods at this site, a collaborative team from Michigan Technological University ("Michigan Tech") and the Les Cheneaux Watershed Council (LCWC) aimed to continue implementing and evaluating EWM biocontrol techniques. We proposed an adaptive management approach that evaluated the performance of the treatment technique established for control of EWM using the fungal pathogen *Mycoleptodiscus terrestris* (Gerd.), or "Mt", an indigenous organism not altered by genetic engineering. The use of adaptive management builds from the GLRI project "Arresting the spread of Eurasian watermilfoil in Lake Superior" (GL-00E01291-0), led by Dr. Casey Huckins and completed in December 2016 (Huckins et al. 2018); Dr. Huckins was a Co-Investigator for this project.

EWM management in the LCI began in 2007, with support also provided by a 2011 GLRI grant to the Les Cheneaux Watershed Council (GL-00E00809, "Eurasian Watermilfoil Strategic Biological Control Program"). Initial management techniques consisted of using a mechanical harvester to cut EWM beds and artificially augmenting the population of a milfoil weevil native to North America (*Euhrychiopsis lecontei*). Weevil stocking was very effective at decreasing the relative density of EWM in quiet and shallow bays but was less successful where boat traffic was heavy, which corresponds to a large proportion of the LCI nearshore zone as well as priority areas for EWM control. In the summer of 2012, EWM growth in the LCI became so prolific that mechanical harvesting and weevil stocking became virtually ineffective. The community responded by forming a task force chaired by the LCWC, which met with Michigan DEQ aquatic invasive species experts and representatives from the Michigan DNR Fisheries Division, the U.S.Army Corps of Engineers (USACE), and two lake management companies in November 2012 to gather input on the development of a milfoil management plan (now part of LCWC's Dynamic Aquatic Adaptive Management Plan, http://lescheneauxwatershed.org/library/lcwc-management/119-lcwc-dynamic-aquatic-adaptive-management-plan/file). The management plan was developed based on those discussions and after reviewing the EWM control methods used by dozens of lake management associations across the US.

Also in 2012, LCWC began to evaluate *Mycoleptodiscus terrestris* (Mt), a native fungal pathogen that has been under study as a potential biocontrol agent for EWM since the 1980s (Shearer and Jackson 2006). Mt is considered to be indigenous to the LCI and was recovered from watermilfoil growing in the archipelago in 2012, as confirmed by a Research Plant Pathologist at the USACE). Mt is not considered to pose a human health risk, as it does not produce toxins or grow at mammalian body temperatures (Briggs 1991). An early formulation of the fungus was determined to be ineffective at inoculating plants in field trials (Shearer 1994), but Agricultural Research Service (ARS) microbiologist Mark Jackson and USACE plant pathologist Judy Shearer collaborated to develop an improved formulation for commercial bioherbicide applications. Their work has led to the development of a technique for cultivating Mt microsclerotia—small, filamentous clumps that tolerate drying and storage and perform better at adhering to plant surfaces (Shearer and Jackson 2006). In 2013 and 2014, LCWC collaborated with the USDA ARS to conduct test applications of the new formulation to small (0.5 to 1 acre) plots of EWM. The 2013 trials established the appropriate dosage rate and provided data on the effect of pump shear forces on the microsclerotia. Following these trials, a low-shear pump system was developed that can be mounted on a boat and applies an optimal dose of Mt at an even dilution rate, which was available and used for this project. Further small-scale treatment in 2014 resulted in a 77% reduction in EWM biomass compared with untreated control areas 35 days after treatment. At the same time, native vegetation cover in the treated areas has increased significantly since 2012. Table 1 summarizes the history of EWM invasion and management in the LCI by the beginning of this project.

Table 1: Timeline of EWM invasion and management in LCI

2003	MDEQ vegetation survey in Cedarville Bay identified EWM in 78% of surveyed area, representing 16% of overall bay
2006	EWM has expanded throughout Cedarville Bay
2007	LCWC plants over 15,000 milfoil weevils (Euhrychiopsis lecontei) at two sites in Cedarville Bay. LCWC acquires a mechanical harvester to cut EWM.
2008	EWM density is dramatically lower within both stocking sites with concomitant increases in bare substrate and native species
2011	LCWC is awarded a 3-year GLRI grant (GL-00E00809) allowing them to plant 100,000 additional weevils

2012	Rampant EWM growth throughout LCI, EWM control by weevils is limited to the plots where they were stocked, an intensive and expensive process Task force meets with government scientists and lake management experts to draft a management plan for EWM in the LCI
2013	Working with Mark Jackson at the USDA ARS, LCWC treats two one-acre test plots of EWM in Cedarville Bay with the fungal pathogen *Mycleptodiscus terrestris* (Mt).
2014	Two new half-acre EWM test plots in Sheppard Bay and John Smith Bay treated with Mt

Through this project, we implemented the Mt biopesticide treatment, used multi-scale remote sensing to help document EWM presence and treatment responses, deployed detailed field sampling to characterize EWM locations and growth conditions, presented on the project at Great Lakes meetings, and worked closely with the Les Cheneaux Watershed Council for community outreach. A detailed Quality Assurance Project Plan (QAPP) was developed by the project team and approved in September 2016 by the EPA project officer (then Rajen Patel) and Kevin O'Donnell, delegate for the Quality Assurance Manager at the US EPA Great Lakes National Program Office (GLNPO). It was revised by the project team and approved by the EPA in December of 2017 to reflect project changes. An APHIS permit (P526P-16-01796) was obtained by the LCWC in 2016 to apply Mt, with updated directions provided by the EPA in 2017 on where it could be applied. The terms of the permit restricted application to harbor sites with a total application area of less than one acre. This change was reflected in the approved QAPP revision.

While the application permit that was approved reduced the original scope of Mt fungus treatment from up to 10 acres per year to one acre total, it did enable application during the project period, and the application sites were well documented through fieldwork and remote sensing. Comparing one treatment site in the Hessel Marina harbor to two untreated control sites, there was a 60% reduction in biomass 50 days after treatment, and greater than 70% decrease in biomass 70 days after treatment. This compared favorably to the previous Mt treatment testing by the LCWC in 2014, which saw an 85% decrease in biomass. In addition, the 2017 treatment results showed the Mt shifting from healthy growth pre-treatment to darkened stems with discolored, brittle, and missing leaflets and shafts after 70 days, whereas untreated areas continued to show healthy EWM growth 70 days later.

To help address the reduced treatment area, and to take advantage of other projects and local treatment efforts, the QAPP revision documented how remote sensing could be used to not only track the Mt treatment area, but also document the impacts of mechanical harvesting and diver assisted suction harvesting (DASH). The harbor managers in Cedarville performed mechanical harvesting treatments in the summer of 2017, and those areas could be seen and quantified in UAS-collected imagery. For a Michigan Department of Natural Resources (MDNR) funded project (# IS14-2005, "Innovative and Multifaceted Control of Invasive Eurasian and Hybrid

Watermilfoil using Integrative Pest Management Principles"), DASH treatment areas in the Portage Waterway that bisects the Keweenaw Peninsula (see Figure 2) were documented with UAS imagery, and the change in biomass could clearly be identified. When combined with UAS data and satellite imagery documentation of EWM extent for the LCI, these helped demonstrate that high-resolution remote sensing can be valuable tool for mapping and monitoring of Eurasian watermilfoil. These remote sensing methods would likely be applicable and useful for monitoring and tracking other invasive aquatic plants as well throughout Great Lakes nearshore areas.

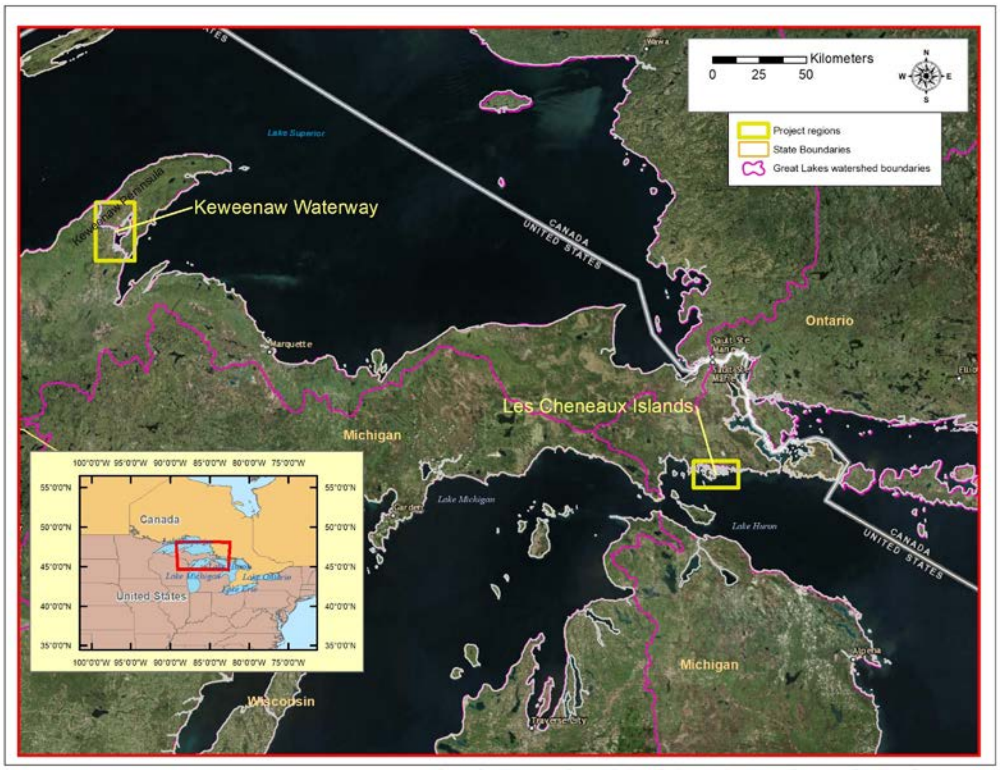


Figure 2: **Primary project location in the Les Cheneaux Islands, with the extended treatment documentation area in the Keweenaw Peninsula.**

The five tasks that correspond to the project's approach areas, summarized in the Executive Summary (planning/permitting, treatment, monitoring, development of application method recommendations, and reporting/outreach), were the main focus of the project work. These are presented in greater detail in Section 4, Project Tasks. Section 5 presents overall conclusions and recommendations stemming from the project, and Section 6 lists the references cited throughout this report.

4. Project Tasks

4.1 Task 1: Planning and Permitting

4.1.1 Permits for management activities

As noted, permitting was focused on obtaining an appropriate permit for application of a liquid culture of Mt as a biocontrol agent. Based on their previous experience with applying the Mt fungus, the project collaborators at the Les Cheneaux Watershed Council travelled to EPA headquarters in July 2017 to get more information on what was permissible for Mt application, building from an APHIS permit obtained in 2016 (APHIS permit P526P-16-01796). The LCWC partners presented on the need for Mt application during the critical summer time period when EWM would be most susceptible to Mt, how it was target specific, highly effective against EWM (and Hydrilla), the planned application areas in Hessel Harbor and Cedarville Bay, details of the field tests, and the application method. Specifically requested was permission to apply Mt in four plats of up to ¼ acre each. Figure 3 shows the areas of Mt application proposed for the permit (in red polygons). Based on this information, permission was granted to apply the native fungus in the restricted areas of harbors in Hessel and/or Cedarville, MI, with the total treatment area not to exceed the one acre approved under the APHIS permit. The permit noted that repeat applications to the same areas within the same season would not add to the total acreage.

Figure 3: Planned application areas of Mt fungus treatment at the Hessel Marina and Cedarville Bay areas in red, as presented to the EPA for approval.

The materials provided to support the application noted that Mt has been shown to be an effective control organism for EWM since the 1980s, that Mt is native to local waters, and has been demonstrated to be safe for other vegetation, animals, and humans. The application method was described as having the following key attributes:

- 45.8 gal/surface acre (Active ingredient rate of 11.4 lbs)
- 11.5 gal per ¼ acre application area (Active ingredient rate of 2.9 lbs)
- Whole culture Mt would be diluted 20:1 using local lake water
- It would be applied via gravity feed from mix tank through a PVC manifold, with the manifold position one foot below the surface, perpendicular to the bow of the pontoon boat.

The EPA recommended that following this approved field trial, an EUP could be obtained in the future that would require including costs of skin irritation studies, obtaining a tolerance exemption for open water studies, and possibly additional data. The LCWC is planning on obtaining an EUP once funding is available to deploy the Mt fungus over a larger area. The reduction in planned treatment area was documented in quarterly reporting and formalized in the QAPP revision. Finally, Clark Township continued to utilize mechanical harvesting and dredging to control aquatic plant growth around public docks and marinas, under permits from the Michigan DEQ Water Resources Division (#13-49-0077-P) and USACE (#LRE-2013-00695-16-S13, exp. 2023).

4.1.2 Quality Assurance Project Plan

At the beginning of the project, a Quality Assurance Project Plan (QAPP) was developed based on the approved statement of work from the project proposal, using the team's best scientific knowledge and experience from previous GLRI and related projects. The approved QAPP development was led by PI Colin Brooks with input from Co-Investigators Dr. Amy Marcarelli, Dr. Casey Huckins, and Amanda Grimm. The QAPP, approved in 2016, served as the overall guide to the project to ensure collection of quality data that would meet the project's needs. Its five tasks matched those in the project proposal and helped ensure that the quality of collected information met the needs of the project. Copies of the QAPP are available by contacting PI Brooks, and is on record with the US EPA GLNPO and the Michigan Tech Project Quality Assurance Manager, Joanne Polzien.

The 115 pages of the QAPP covered task descriptions (Element A) and data generation/acquisition (Element B). Among the highlights of Element A were descriptions of key project personnel, additional background on the EWM problem in the area, a listing of potential test locations for Mt treatment, reviews of previous benthic response monitoring, a review of remote sensing-based methods for monitoring, vegetation survey methods, water chemistry data collection methods, project documentation plans, and instrument calibration methods. Additional attachments covered the original planned participation of the USDA Agricultural Research Service (before they unexpectedly announced they would no longer be growing Mt), previous survey results show methods from 2014, the planned data sheet covering water and vegetation surveys, YSI sonde calibration specifics, and standard operating procedures for Enviroscience milfoil/vegetation survey transects.

Most of this QAPP served through the duration of the project. A six page revision was drafted in 2017 and approved by GLNPO to reflect needed changes. Two revisions to the original QAPP were included. One reflected a scaled-down plan to deploy the Mt fungus that meet the requirements of the APHIS permit that was approved after the project was proposed,where Mt fungus deployment would be limited to harbor sites (not open water areas that would include swimming areas or drinking water intakes) and would need to be less than once acre total. The other revision reflected that an alternative source for Mt fungus being grown had to be obtained from Wisconsin Bioproducts (http://wisbio.com/) after the USDA ARS was no longer able to provide it, and that the <one acre total area meant that small plots in the Hessel and Cedarville harbor areas were implemented instead of the larger area of up to 10 acres per year for two

years that had originally been planned. Two new sections in the QAPP revision captured the addition of using remote sensing to document the impacts of two additional treatment methods, the previously mentioned mechanical harvesting being done under the auspices of the local township, and the diver assisted suction harvesting (DASH) that was done under the MDNR invasive species grant. While these were not tasks completed for this project, the project team was able to use the fact that they were happening to demonstrate additional value in using high-resolution UAS-enabled remote sensing to monitor treatment types.

4.2 Task 2: Treatment

The most common treatment method for invasive watermilfoils is chemical herbicide. However, in some invaded areas, herbicide application is infeasible, prohibited or just undesirable. The Les Cheneaux communities are not open to aquatic herbicide application in their waterways due to the perceived risk of drinking water contamination (many lakefront properties have private water intakes for household water supplies). Thus, EWM management in Les Cheneaux waterways has been a combination of biocontrol and manual removal activities. The treatment component of this project focused on biocontrol with Mt fungus as previous efforts in the area had led to it being close to practical deployment.

In the proposal for this project, the U.S. Department of Agriculture Agricultural Research Service provided a letter of support from Research Biologist Dr. Mark Jackson, who was going to ferment and provide the needed amounts of Mt and transport it under refrigeration from the fermenter at a USDA facility in Peoria, Illinois. This would have provided the ability to apply Mt fungus in both 2016 and 2017, as originally planned. However, the project team learned in the summer of 2016 that Dr. Jackson's office would no longer be providing Mt growth capabilities to anyone, so a new source of Mt fungus had to be found, as documented in the project semi-annual report that covered April - September 2016. Over the winter of 2016-2017, a new source was found in Wisconsin BioProducts (http://www.wisbio.com/); LCWC staff negotiated with them to ferment Mt for the 2017 treatment season. The USDA lab did provide WisBio with the initial culture, so the Mt strain intended for treatment (USDA TX-05) remained the same.

In October of 2018, Bob Smith and Mark Clymer of the LCWC submitted a final report to PI Brooks that detailed the Mt fungus application, entitled "Use of Use of *Mycoleptodiscus terrestris* as a mycoherbicide for *Myriophyllum spicatum* (Eurasian watermilfoil) management in the open-water system of the Les Cheneaux Islands, Michigan". The full report is available from PI Brooks and is being posted to the LCWC webpage at http://lescheneauxwatershed.org/.

For the treatment effort, Mt culturing was complete with a whole culture harvest at Wisconsin Bioproducts on July 26, 2017. The liquid culture was chilled to 4℉, transferred into five gallon (20L) carboys, and stored in Styrofoam containers placed inside 16 protective cardboard shipping boxes. These boxes were loaded into a pickup truck, layered with dry ice, covered by plastic tarp, and driven from Milwaukee to the Les Cheneaux Islands. The boxes were stored on the truck until the application day of July 28th, 2017. The dry ice was still present between the shipping boxes, and Mt culture temperatures ranged from 39 to 44℉ (3.9 to 6.7℃) at application time.

Figure 4 shows the Mt being applied using gravity feed from a mix tank on board an available LCWC vessel, as planned. Also as planned, it was applied at a rate of 45.6 gal/acre with dilution with local lake water at a 20:1 ratio per volume of Mt, which improved Mt distribution through the plot. Mt was applied at the Cedarville launch ramp (CRAMP) area totalling 37,865 ft^2 (0.8692 acres) and at Hessel Marina area totalling 7,040 ft^2 (0.1616 acres). Additional areas that received Mt were at the Cedarville Marine marina (corresponding to the FDS sampling site) at 0.2181 acres, Breezeswept at 0.2202 acres), and Bumpa's waterfront (corresponding to our Court East sampling site) at 0.2410 acres (Figure 5). Only the Hessel Marina site was monitored for quantitative analysis due all other areas being comprised for monitoring by mechanical harvesting by the local business responsible for them. The CRAMP site was monitored on a qualitative basis because the EWM growth was so dense at the time of Mt application that quantitative monitoring was not possible.

Figure 4: Example photos of the Mt fungus being applied on July 28, 2017 from the LCWC vessel with the customized boom.

Figure 5: Locations of the project data collection sites: Les Cheneaux Islands (Hessel and Cedarville) and the Keweenaw Waterway.

At the Hessel Marina site, plant biomass surveys were performed on the day of treatment, 25 days after treatment (DAT), 35 DAT, 47 DAT, and 70 DAT by the LCWC. Also, the Michigan Tech team performed monitoring of the area June 19-23, 2017; July 13-15, 2017; and August 21-25, 2017 to help with pre- and post-treatment assessment during the treatment year. Follow up surveys by the combined team also were completed in 2018, and initial pre-treatment surveys were completed in 2016 (see Task 3).

The application of Mt fungus to the Hessel Harbor marina location resulted in over 70% biomass loss at 70 days after treatment as compared to two different untreated control sites. To achieve efficacy this similar for field trials conducted three years apart was a very positive result. Having the Mt culture produced by two different laboratories and achieving the observed degree of EWM control was also encouraging. One year after treatment, the LCWC found that the EWM biomass in the previously treated area was one-half the biomass recorded for an untreated area. This limited evaluation suggests that EWM vigor might be reduced during the season following Mt treatment, based upon EWM biomass in previously treated and untreated areas. If annual reduction in EWM vigor were to occur during successive annual Mt treatments, it is possible that multiple Mt applications could reduce EWM growth to a “minimum nuisance macrophyte” relative to aquatic ecology and recreational activities. Moreover, there continues to be appear to be no obvious impact on non-target macrophytes.

4.3 Task 3: Monitoring

4.3.1 Task 3a. Remote sensing-based monitoring and mapping

Remote sensing was used as a tool to help map the extent of EWM, and to show how high-resolution imagery can be used to track the effects of management efforts. The remote sensing work used several components to meet these needs, including:

- Using commercially-available high resolution satellite imagery to map the extent of EWM and other other SAV.
- Developing spectral profiles to document how EWM can look different than other vegetation and bottom types, to help with the mapping process.
- Using unmanned aerial systems (UAS, also unmanned aerial vehicles / UAVs, or “drones”) to show how very high-resolution, rapidly deployable imaging systems can help with mapping mapping and monitoring.

Both the satellite- and UAS-enabled remote sensing activities built on previous work supported by GLRI and NASA, such as the GL-00E01291-0 project (see the Huckins et al. 2018) and methods documented in Brooks et al. 2015 and Shuchman et al. 2013 developed under GLRI funding, among other sources (http://www.mtri.org/cladophora.html). Current UAS technology provides up to approximately 20 minutes of flight time in systems costing less than $10,000. Also, standard rules from the Federal Aviation Administration (FAA) that went into effect in 2016 (called “Part 107”) provide clear direction that UAS flights must be limited to within line-of-sight and no higher than 400 feet (122 m). This limits the area that can be covered by a low-cost UAS operating under Part 107. To map larger areas, satellite imagery is more practical, although at lower resolution. The project proposal had the goal of using satellite imagery to map at least an 800-acre area for SAV including EWM, which was completed. While species-level identification is more difficult with commercial multispectral satellite imagery, it can provide at least a screening tool to identify areas of higher- or lower-density SAV that can then be surveyed with higher-solution UAS imagery for more detailed mapping.

4.3.1.1 Satellite mapping

Given that 2012 was the year of peak EWM growth and therefore should be the year for which EWM is easiest to map, a spectral-based classification method was developed using a summer 2012 Quickbird satellite image (resolution 2 m / 6.6 ft). However, as the more intensive annual EnviroScience vegetation surveys were initiated in 2013, no field data were available, so an unsupervised method was utilized. The final classification (Figure 6) covers 1730 acres and includes four spectrally separable submerged aquatic vegetation (SAV) classes as well as a deep-water/dark SAV class, a sparse SAV class, and a floating aquatic vegetation class. Based on field and aerial photos and qualitative information on vegetation growth and distribution in 2012 provided by the LCWC, it is likely that the class ‘SAV 2’ represents a dense monoculture of EWM, ‘SAV 1’ represents a mixture of lower-density EWM and other SAV species, ‘SAV 4’ represents mixed SAV and floating-leaved vegetation with an EWM component, and ‘SAV 3’ primarily represents benthic algae. This map demonstrates that satellite imagery can be used for initial mapping of surface aquatic vegetation vs. submerged aquatic vegetation even in the absence of field data.

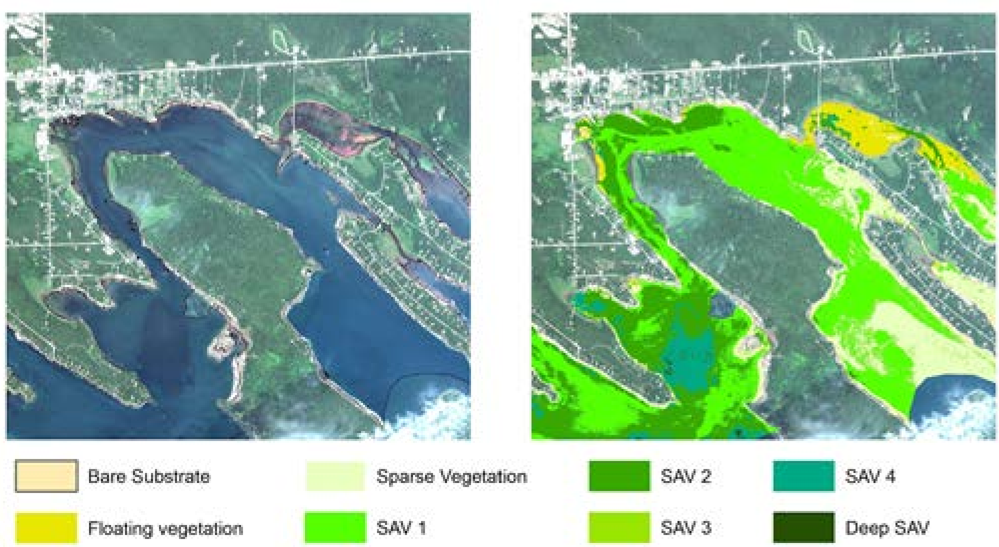


Figure 6: Classified SAV map of Cedarville and Sheppard’s Bays in Les Cheneaux, summer 2012.

More recently, a second satellite-based pre-treatment map of Cedarville Bay and Sheppard’s Bay was classified for a 750-acre area from a cloud-free WorldView-3 image (resolution 2 m) collected June 30, 2016. This second map reflects the lower-density EWM conditions present in the Les Cheneaux waterways just before Mt treatment, and utilizes the point-intercept data collected by EnviroScience in summer 2016 to inform the class names. This map was created using the Maximum Likelihood Classification tool in ESRI ArcGIS, using the point intercept data to create the input class signatures. An accuracy assessment of this map (Figure 7), performed using a subsample of this field data, indicated an overall map accuracy of 87.4% (Table 2). The performance of this approach demonstrates that spectral-based unsupervised classification tuned with field data can be an effective technique for mapping EWM. The map results indicate dense EWM growth in the northwest corner of Cedarville Bay and inner Sheppard's Bay, which agrees with the field data, as well as selected areas along La Salle Island that were not specifically sampled during the fieldwork.

Figure 7. Classified map of 2016 aquatic vegetation cover in Cedarville and Sheppard's Bays, Les Cheneaux Islands.

Table 2. Error matrix for the classified map shown in Figure 7, based on coincident field truth data.

	Bare	Schoenoplectus	Algae	EWM	SAV (non-EWM)	Typha	ACTUAL	PRODUCER'S ACCURACY
Bare	5	0	0	0	0	0	5	100.0%
Schoenoplectus	2	1	0	1	0	0	4	25.0%
Algae	8	0	25	0	0	0	33	75.8%
EWM	0	0	0	3	0	0	3	100.0%
SAV (non-EWM)	0	0	0	0	38	0	38	100.0%
Typha	0	0	0	0	0	4	4	100.0%
PREDICTED	15	1	25	4	38	4		
USER'S ACCURACY	33.3%	100.0%	100.0%	75.0%	100.0%	100.0%		
TOTAL ACCURACY		87.4%						

4.3.1.2 Spectral profiles

To help understand how EWM can be identified in aerial and satellite imagery, spectral profiles showing the remote sensing reflectance (Rrs) of different submerged aquatic vegetation (SAV) types were collected by the Michigan Tech team using two types of spectroradiometers. These spectroradiometers were an ASD FieldSpec 3 and a MTRI-built Lightweight Portable Radiometer (LPR) which recorded the amount of reflected light in wavelengths from 350 nm to 1000 nm (ultraviolet to near-infrared, including visible light). The spectral data collections were completed at three different scales of spectral profiles: SAV species removed from the water to obtain a direct vegetation profile without water column influences (out-of-water or "OOW data"), profiles of submerged vegetation collected from the side of the boat with the radiometer held approximately three feet above the water ("boatside" data), and spectral profiles collected from the LPR radiometer flown onboard a UAS at approx. 10–15 m above the water ("LPR UAS" data). Figure 8, from Brooks et al. (under review) shows the methods used to collect the spectral data, including the LPR system.

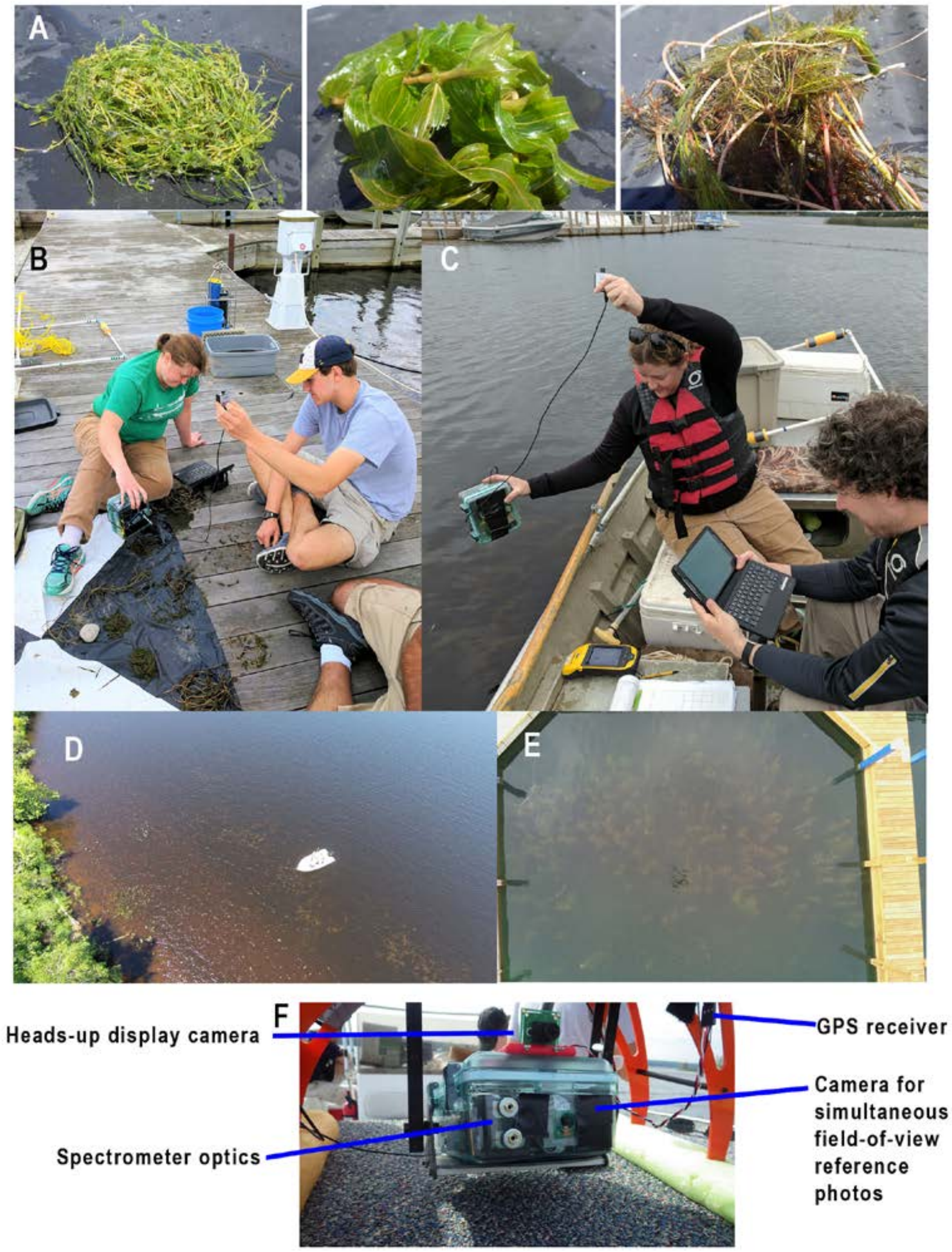


Figure 8. Images demonstrating spectral data collection methods. (a) Single-species plants on a black tarp about to have their spectral profile recorded for out-of-water (OOW) scale data. From left to right: *Chara sp.* (stonewort), *Potamogeton richardsonii* (clasping-leaf pondweed), and EWM. (b) Collection of OOW scale data using the LPR spectroradiometer during an August, 2017 data collection (c) Collection of spectral profile data at the boatside scale using the LPR spectroradiometer over an area of predominantly EWM. (d) Initial aerial photo test from 2015 at a site in Keweenaw Waterway showing visible submerged aquatic vegetation, emergent vegetation, shoreline vegetation along with the Michigan Tech research vessel used for launch and recovery of a DJI Phantom UAS. (e) Aerial photo taken from the Bergen hexacopter UAS with the LPR's five mp camera, with EWM visible near the water's surface at a boat slip in the

Hessel Marina site in the Les Cheneaux Islands study area. (f) The LPR mounted underneath the Bergen hexacopter UAS, about to collect spectral data over an area of EWM (including hardware notations).

Table 3 lists all the places that spectral data were collected, helping to identify the spectral signatures of EWM and other macrophytes (See Figure 5 for their locations).

Table 3. Collection sites listing types of spectral data collected by time period and data collection scale. *Scale and method of spectral data collection: OOW = out-of-water; Boatside = from side of boat; LPR UAS = Light Weight Portable Radiometer from an unmanned aerial system*

Collection Sites	Region	June 2015	July 2016	August 2016	June 2017	July 2017	August 2017
Pike Bay	Portage Waterway	OOW		LPR UAS			
Torch Bay	Portage Waterway	OOW					
Breeze-swept	Les Cheneaux Islands					Boatside, LPR UAS	Boatside, OOW
Cedar	Les Cheneaux Islands						OOW
Court Dock	Les Cheneaux Islands		LPR UAS				
Court East	Les Cheneaux Islands		Boatside, LPR UAS	Boatside	Boatside, LPR UAS	Boatside	Boatside, OOW
Court West	Les Cheneaux Islands					Boatside	OOW
Chappell	Les Cheneaux Islands				Boatside		Boatside, OOW
FDS	Les Cheneaux Islands		Boatside, LPR UAS	Boatside, LPR UAS	Boatside, LPR UAS	Boatside, LPR UAS	OOW
Hessel Marina	Les Cheneaux Islands					Boatside, LPR UAS	Boatside, OOW
Howells Dock	Les Cheneaux Islands			Boatside, LPR UAS	OOW, Boatside, LPR UAS		Boatside, OOW
Neil	Les Cheneaux Islands				Boatside, LPR UAS	Boatside, LPR UAS	Boatside, OOW

Under the right water and light conditions, certain spectral bands, and depending on the growth patterns, the spectral profiles of EWM did appear to be distinct from those of other aquatic vegetation species and bottom types. This was particularly true when the Normalized Difference Vegetation Index (NDVI) was included as a predictor. NDVI is a reflectance ratio of near-infrared to red light that is able to indicate different amounts of vegetative biomass. These methods have been documented in Brooks et al. (under review), the first journal article in PI Brooks' PhD dissertation that focuses on SAV mapping methods and applications.

Figure 9 shows an example of spectral profiles of EWM and other vegetation types when the plants were taken out of the water to get the strongest spectral signature possible. These use all 651 one-nanometer(nm)-wide spectral bands from 350 to 1000 nm. The two-sample

Kolmogorov-Smirnov (K-S) test (Sokal and Rolf 1995) used in R (versions 3.4.0 to 3.4.3) reveals that when using all available spectral bands, EWM does look different than other vegetation species. However, this does not provide a practical imaging system for EWM mapping, as available multispectral and hyperspectral systems more typically from four to 80 bands.

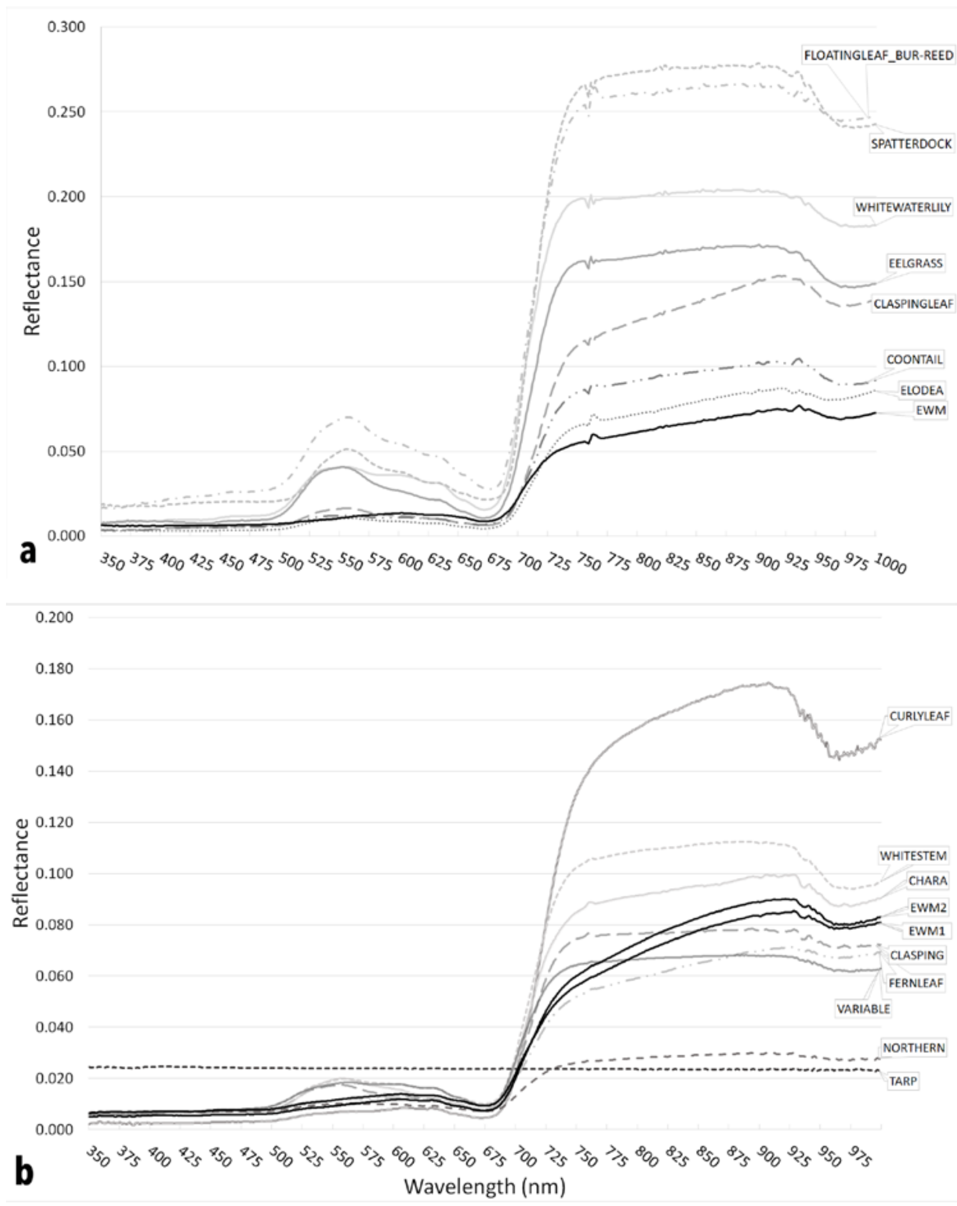


Figure 9. Spectral profiles for out of water vegetation. (a) Spectral profiles of eight OOW aquatic plant species from June 2015, showing ultraviolet to near-infrared (350–1000 nm) wavelengths for all 651 bands. (b) Spectral profiles for nine aquatic plant species, plus a reference tarp, from June 2017, showing all 651 one nm wide bands.

Figure 10 shows spectral data resampled to two levels: one representing six spectral bands that correspond to a Tetracam MCA-6 imaging camera that was available for summer field work in

(12a & 12c), and other for eight bands that correspond to those found useful for wetlands mapping by Becker et al. (12 b & 12 d) (Becker et al. 2005, 2007). 12a and 12b show 2015 OOW data, while 12c & 12d show 2017 data.

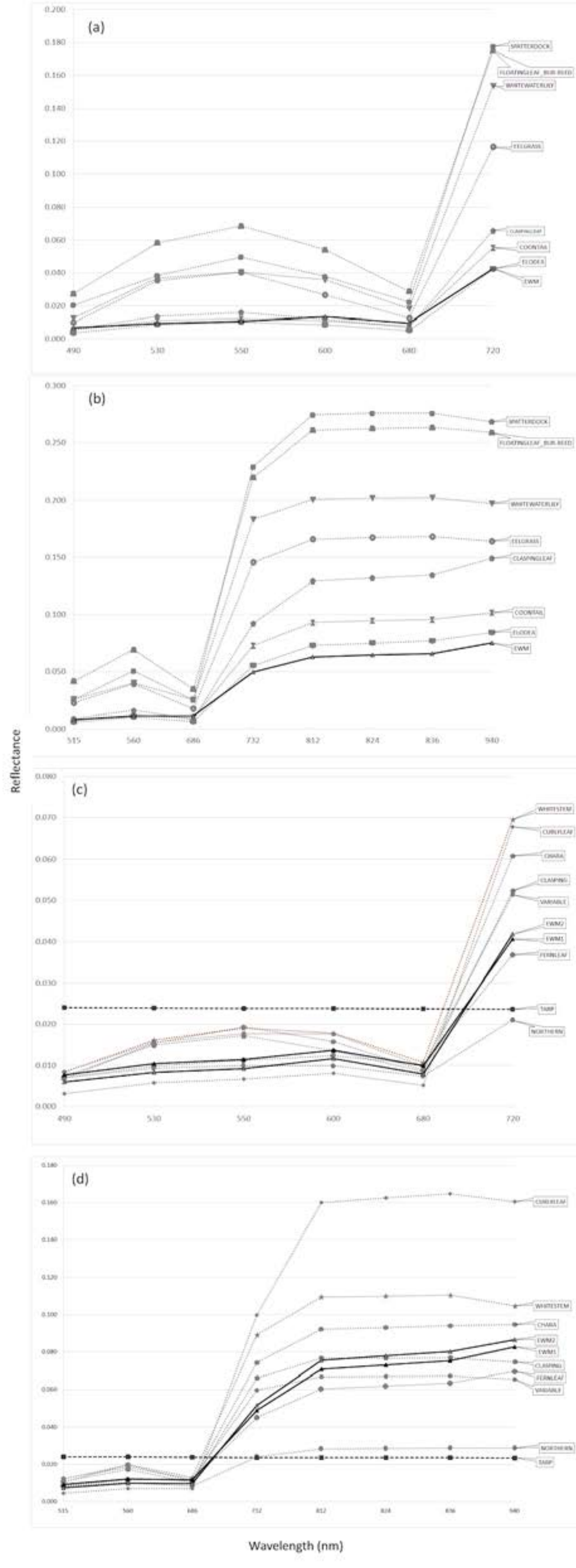


Figure 10. Resampled spectral reflectance values for Tetracam and Becker spectral bands: (a) Resampled to approximate the Tetracam bands for the eight OOW species samples collected in 2015. (b) Resampled to the Becker bands for the 2015 OOW data. (c) Spectral reflectance values for the Tetracam wavelengths for the nine out-of-water species collected in June, 2017. (d) Spectral reflectance values for the Becker wetland bands for the nine out-of-water species collected in June 2017.

Using just the spectral data equivalent to the Tetracam and Becker bands did not result in reliable differentiation of EWM spectra from other vegetation types when using the K-S test. However, average all 651 bands to just 65 10-nm wide bands did result in EWM being different from nearly all other vegetation types when using June of 2017 OOW data. This supports the concept of deploying a hyperspectral imaging system with a number of bands similar to the 65 averaged bands tested here as a reliable way of identifying EWM from other vegetation types.

Also analyzed were 62 spectral profiles representing all the boatside-scale data collected in 2016 and 2017. A two-way ANOVA mixed model was the analysis showed that NDVI values were significantly different among dominant vegetation groups. Two aquatic vegetation indices were investigated as well (the Normalized Difference Vegetation Index and the Water Adjusted Vegetation Index, see Villa et al. 2014) but did not help differentiate EWM from other SAV.

When comparing the LPR UAS, boatside, and OOW spectral data for EWM samples, the LPR UAS data only averaged 13.3% of the boatside remote sensing reflectance and 27.4% of the OOW values. The lower values for the LPR UAS data are most likely caused by the greater distance to the spectroradiometer sensor when it was been flown 30-45 feet in the air vs. the boatside and OOW spectral data collection. Maximizing the amount of information reaching a UAS-based camera by collecting on sunny days, near solar noon, and with relatively calm waters should help strengthen the signal of vegetation profiles when using this more distant method of vegetation profiling.

4.3.1.3 UAS mapping

UAS-collected imagery provided an important resource for documenting EWM extent. UAS imagery was used both for EWM mapping and more generally for documenting treatment locations. Figure 11 shows the treated Hessel marina area on August 24, 2017 (27 days after Mt treatment) in a natural color image, where EWM is clearly identifiable as the tall, feathery stems reaching near the water's surface. The MTRI team created several natural color orthomosaics using DJI Mavic Pro, Phantom 3 Advanced, Nikon D800 and Nikon D810 camera systems. After obtaining the imagery, the team used Agisoft Photoscan to create orthomosaic base maps of each site. To create these, Agisoft takes individual image frames and merges them together using their GPS locations and GPS ground control points. It creates a 3D point cloud of each site that is used to create the 2D orthomosaic.

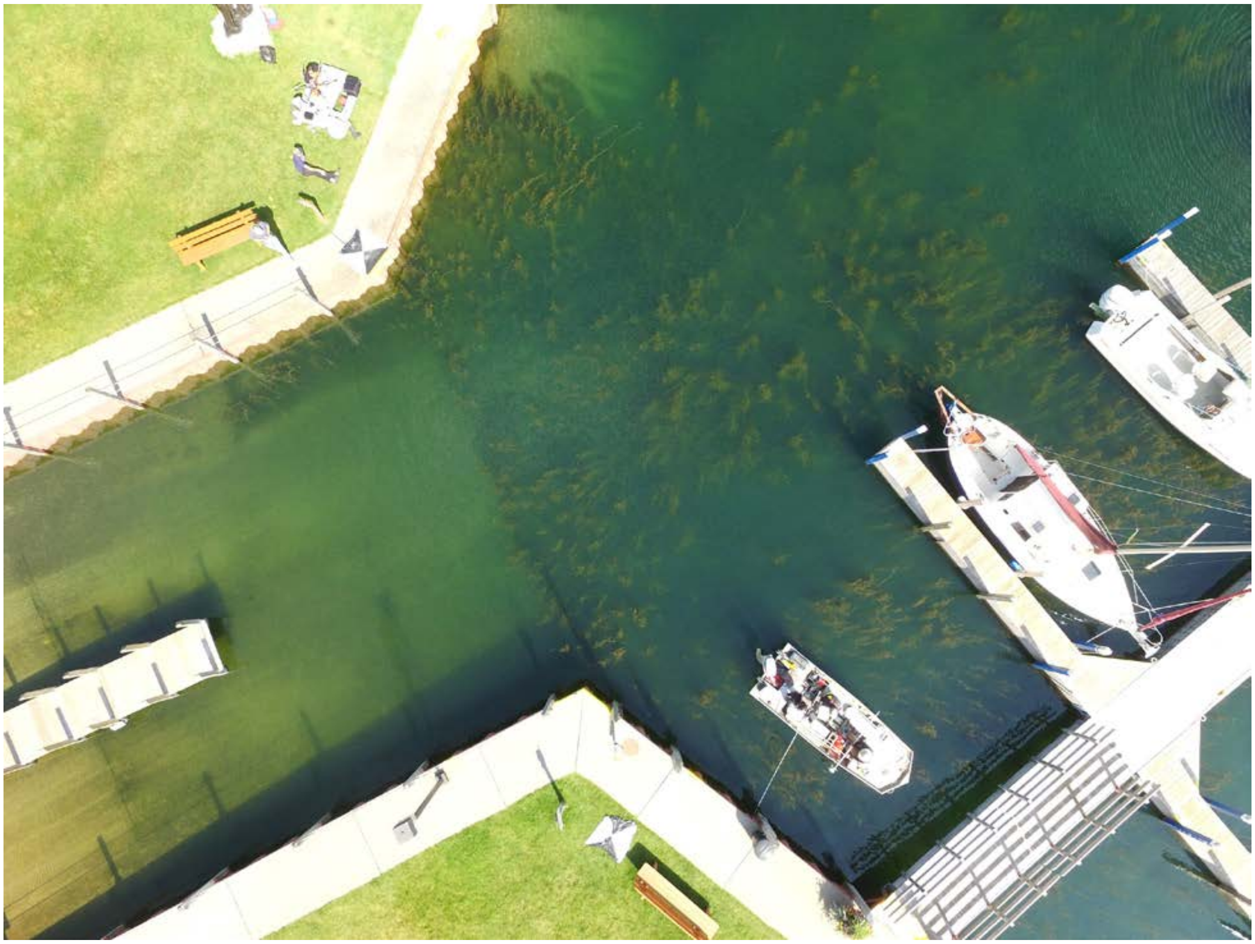


Figure 11: Example UAS-collected image from 8/24/2017 of the primary Mt treatment location in the Hessel marina. The dense feathery vegetation near the water's surface is EWM, which can be clearly identified in the UAS imagery.

Once the orthomosaics have been created, the next step is to create supervised classifications using eCognition Developer software. Once the imagery has been loaded into the program, we execute a command called multiresolution segmentation on each image. This command groups similar pixels into polygons based on spectral similarities to neighboring pixels. Once this step has been completed, we next create all of the image classes and begin identifying regions where examples of each class exist in the imagery. After supplying sufficient training data to the program, we next execute the classify step. This command uses the supplied training data to assign each pixel a class based on pixel parameters such as color and brightness. Once complete, the generated classification is exported to create figures of the classification. Figure 12 below is a classification example at Howells Dock. This natural color orthomosaic (top) was taken in 2016 using a Nikon D800 digital camera with 36-mp resolution. One of the dominant vegetation types for this site was Eurasian watermilfoil (indicated in yellow in the classification, bottom).

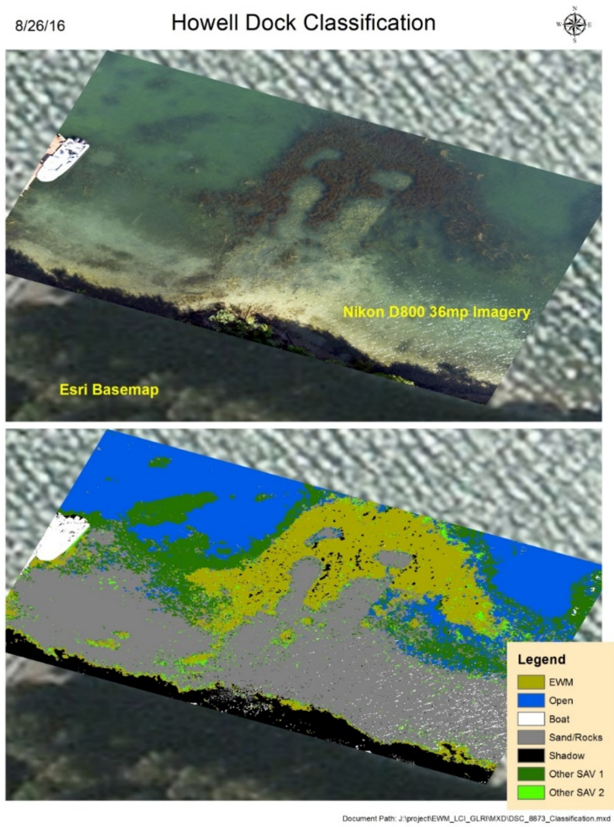


Figure 12: Classified map (bottom) derived from an orthomosaic (top) of imagery collected in August 2016 using an UAS-flown Nikon D800 at the Howells Dock site (see Fig. 5).

In addition to natural color images (also known as red/green/blue or RGB images), multispectral images were also collected using two systems that could image in the both the visible and near-infrared ranges. These were a six-band Tetracam multispectral camera and a system that combined two Canon cameras. For the two Canon camera system, called the VISNIR system, one was a normal camera sensitive to visible RGB light, and the second camera was sensitive only to near-infrared (NIR) light. Collecting imagery in this way made it possible to generate a NDVI layer using both the NIR and RGB imagery. Once created, the RGB, NIR and NDVI images were layered together in order to create the classification in eCognition. The near-infrared light, along with the NDVI, were useful for identifying areas of heavy vegetative biomass near the water's surface, which was often EWM.

Figure 13 presents an example of this method for the Court East project site (see site map in Fig. 5). The left map panel shows the VISNIR data displayed as an RGB image, and the right panel shows the results of object-based classification performed on the VISNIR bands and derived NDVI. Instead of using Agisoft Photoscan to process this imagery, we used ESRI ArcMap to georeference individual image tiles to their respective locations. We used GPS points and the ESRI basemap imagery to align these images correctly.

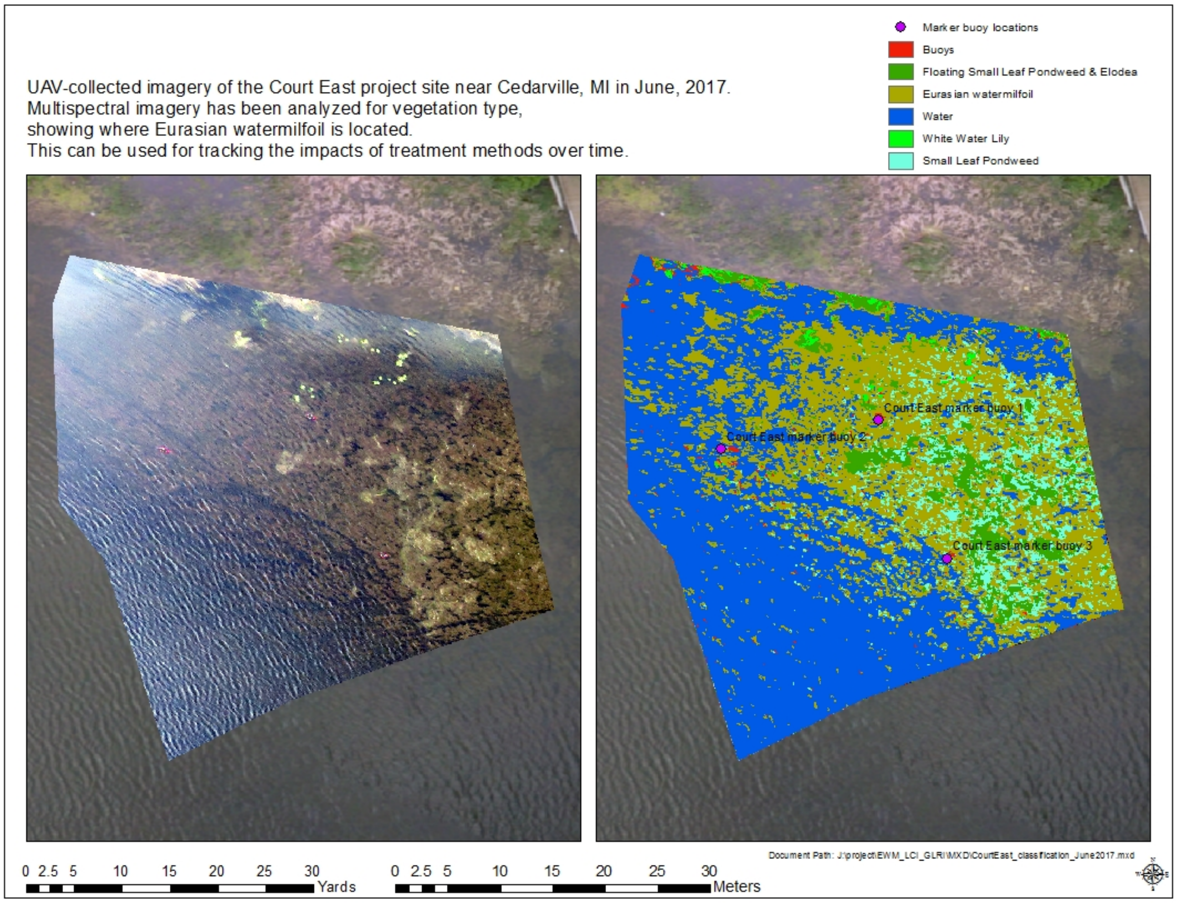


Figure 13: Example classification based off VISNIR imagery and NDVI for the Court East site with June, 2017 UAS images.

The other multispectral system used was the six-channel multispectral camera manufactured by Tetracam (Chatsworth, California; http://tetracam.com/), the MCA-6 system, whose bands were investigated with spectral data. This was selected for its ability to cover the 400–1000 nm (visible to near-infrared) spectral range, the availability of different spectral filters within that range, company reputation, and low weight (<one kg / 2.2 lbs with battery). The system was available for three one-week data collection periods in 2016 and 2017 via rental. After demonstrating its value, it was purchased by Michigan Tech for use in 2018. The Tetracam Micro MCA-6 was configured with the following bands: 490 nm (blue), 530 nm (green 1), 550 nm (green 2), 600 nm (orange), 680 nm (red), and 720 nm (red edge). Preliminary data collected in 2015 in the Keweenaw Peninsula was used to help select these specific bands as potentially informative. An example of classified Tetracam imagery is shown below in Figure 14. Here, georeferenced Tetracam multispectral imagery has been laid over Nikon D800 and DJI Phantom imagery. Through the use of multispectral imagery, we were able to differentiate between Eurasian watermilfoil and Northern watermilfoil. Northern watermilfoil appears bright green, while Eurasian watermilfoil appears reddish-brown in the multispectral images.

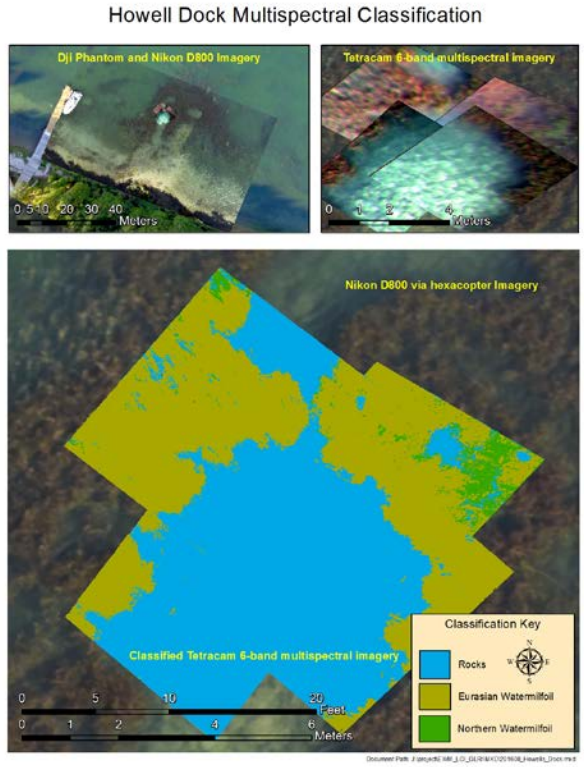
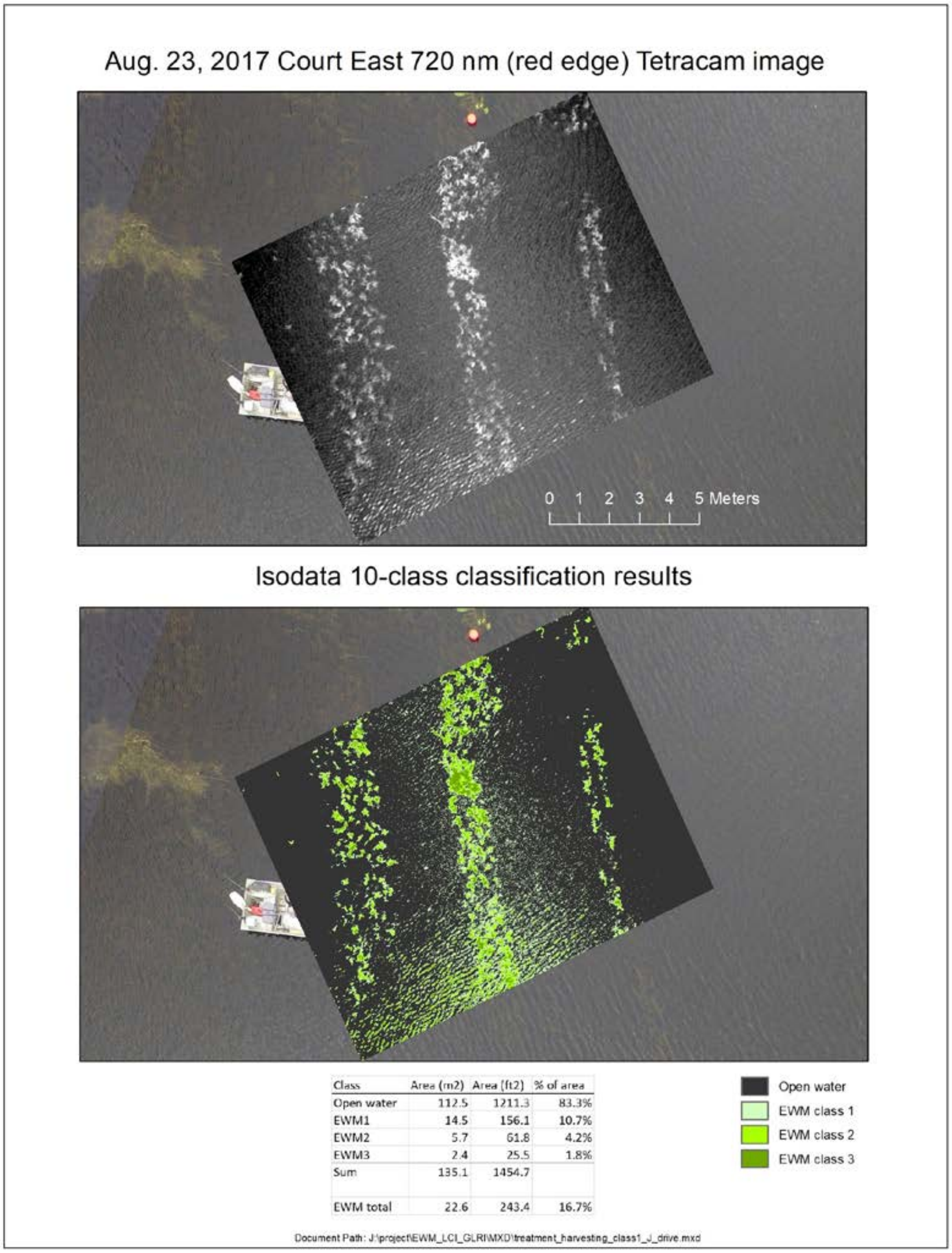


Figure 14: Classified Tetracam multispectral imagery comparing coverage of Northern to Eurasian watermilfoil at Howell's Dock.

UAS imaging was focused on monitoring the Hessel marina treatment site and nearby untreated control sites as a reference. During the project, the opportunity to document two other treatment types became available. Mechanical harvesting by local marina operators took place in Cedarville in early July 2017, and the effects of this mechanical removal of EWM could be seen in RGB UAS imagery collected on July 19, 2017 and in multispectral imagery collected on August 23, 2017 (Figure 15). Specific quantitative data could be calculated from the Tetracam image in Figure 15, where 83.3% of the mechanically harvested area (1211.3 ft^2) was open water after treatment, but 16.7% (243.4 ft^2) of the 1454.7 ft^2 (0.03 acres) imaged area was still in EWM. This shows how UAS-enabled multispectral sensing can help with monitoring the mechanical harvesting treatment type by documenting remaining vegetation after treatment.



Class	Area (m2)	Area (ft2)	% of area
Open water	112.5	1211.3	83.3%
EWM1	14.5	156.1	10.7%
EWM2	5.7	61.8	4.2%
EWM3	2.4	25.5	1.8%
Sum	135.1	1454.7	
EWM total	22.6	243.4	16.7%

Figure 15: Demonstration of using UAS multispectral Tetracam imagery to document effectiveness of mechanical harvest treatment method.

Additionally, the “Innovative and Multifaceted Control of Invasive Eurasian and Hybrid Watermilfoil using Integrative Pest Management Principles” project funded by Michigan DNR provided the opportunity to image areas of diver-assisted suction harvesting (DASH) treatment immediately before and after the treatment took place. There were five DASH plots, totalling 1141 ft^2 or 0.0262 acres. Figure 16 show how changes in EWM near-surface biomass due to DASH removal can clearly be identified in the near-infrared (NIR) imagery collected by UAS of the DASH plots. Figure 17 shows classification analysis results using the post-DASH imagery, where the lack of EWM biomass after treatment can clearly be seen after treatment within the four DASH plots covered by the UAS imagery. Using pre- and post-DASH classifications, the amount of EWM within those four plots dropped from 25.1% of the plot areas to only 2.7% after DASH treatment (Table 4). These results also show how quantitative data on DASH treatment effectiveness can be obtained using UAS imagery.

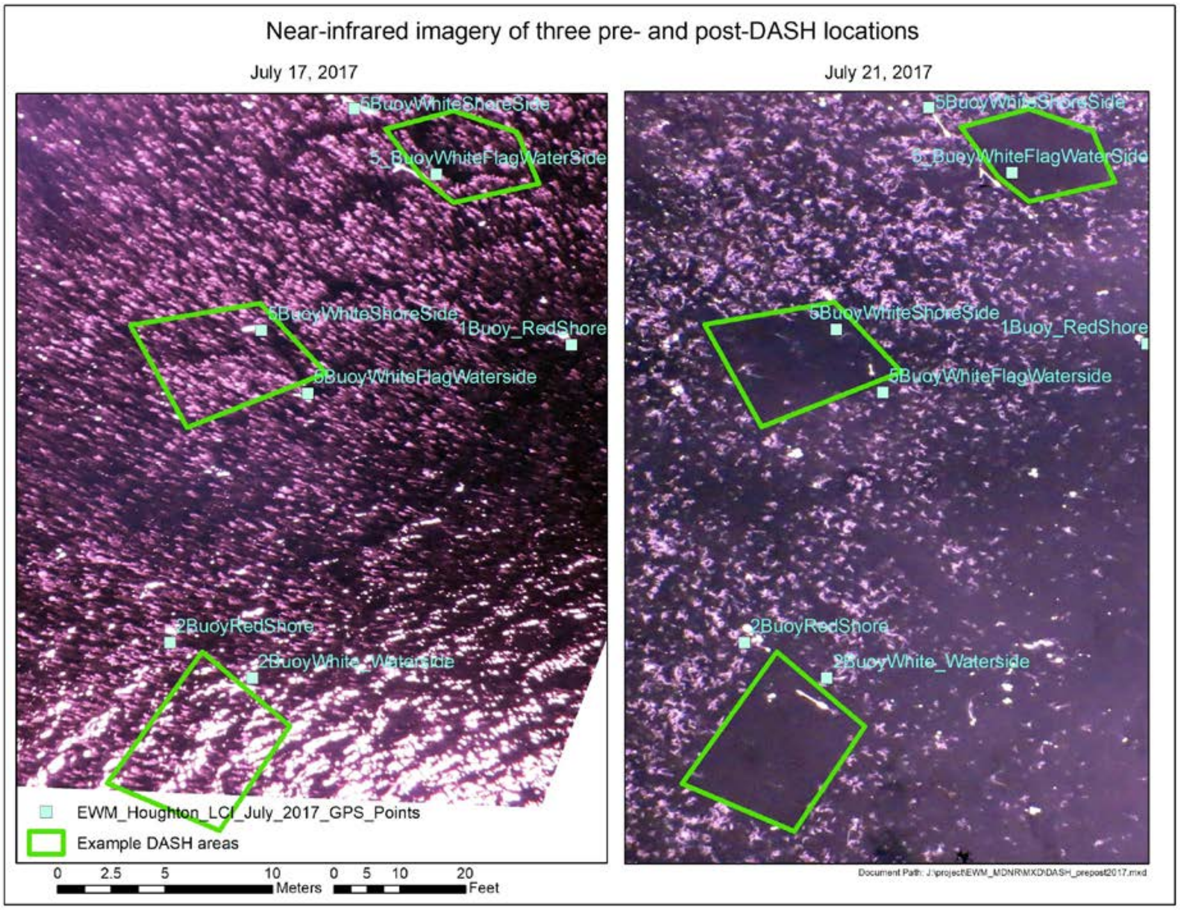


Figure 16: Examples of NIR imagery collected via UAS showing changes in EWM extent before and after DASH treatment in July of 2017.

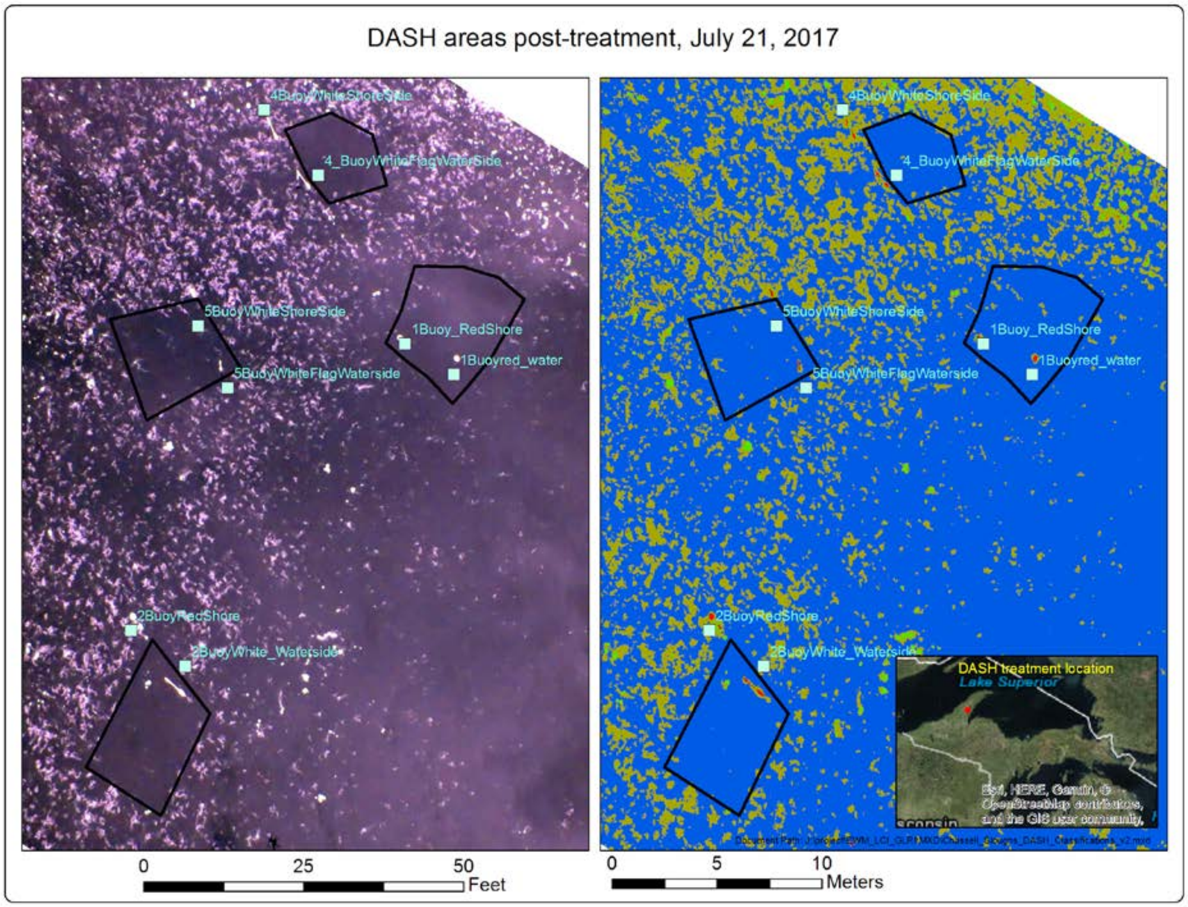


Figure 17: Mapping results for the four DASH treatment plots covered by VISNIR UAS imagery collected immediately before and after treatment in July, 2017.

Table 4: Area in ft^2 of EWM and other types in pre-DASH and post-DASH treatment plots.

Cover type	Pre-DASH	% of area	Post-DASH	% of area
Water	640.59	73.0%	882.77	96.8%
EWM	220.61	25.1%	24.52	2.7%
Buoy	2.41	0.3%	2.65	0.3%
Lillypads / Emergent Veg	14.10	1.6%	2.08	0.2%
	877.70		912.02	

Area units are in ft^2

Figures 18 and 19 illustrate another use of UAS imagery to track EWM treatment, this time using July 2017 and August 2018 natural color (RGB) imagery collected with DJI Phantom 3 Advanced and Mavic Pro UAS. EWM appears dense before treatment in July 2017, but less dense one year later, within a matrix of other SAV species.

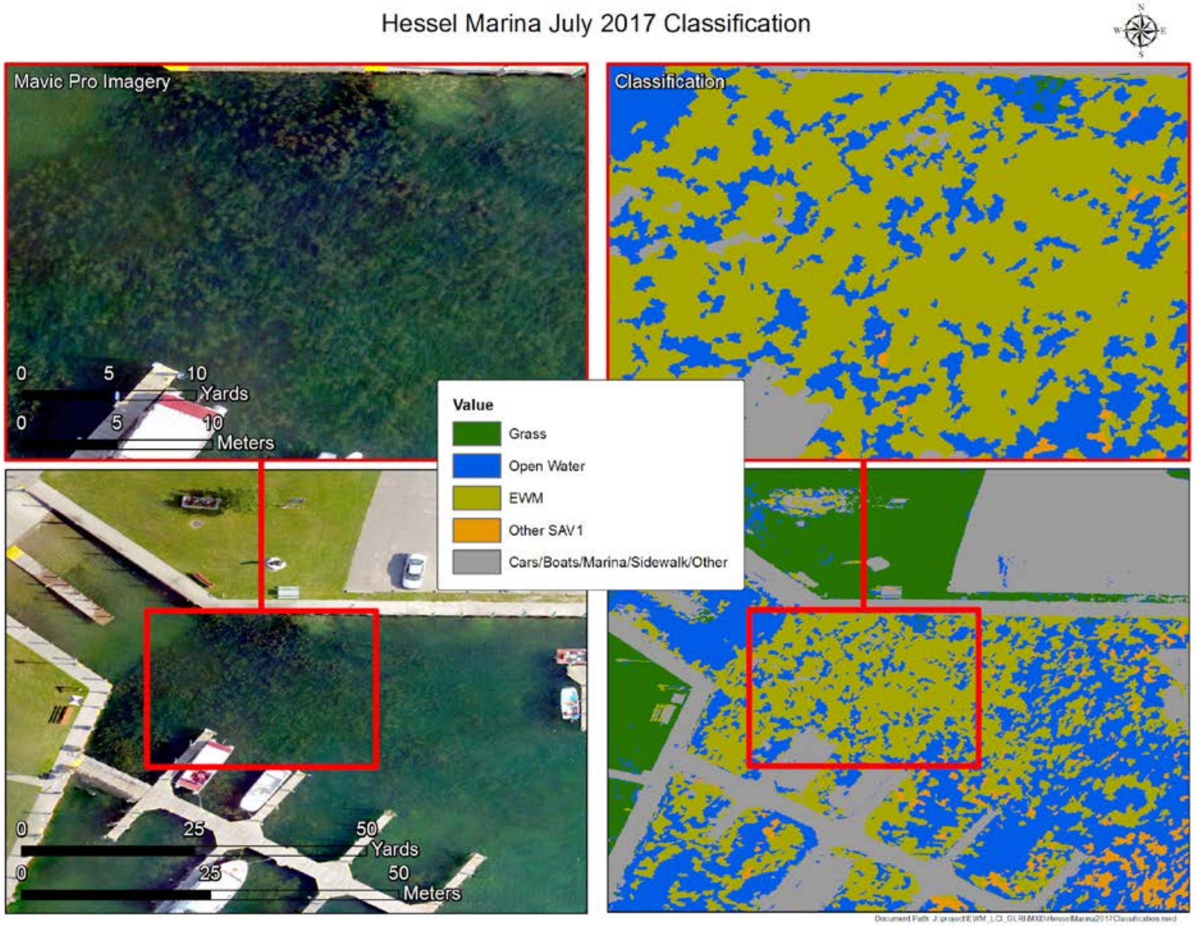


Figure 18: July 2017 images and classification results of Hessel Marina shortly before Mt fungus treatment. EWM is dense within the marina area.

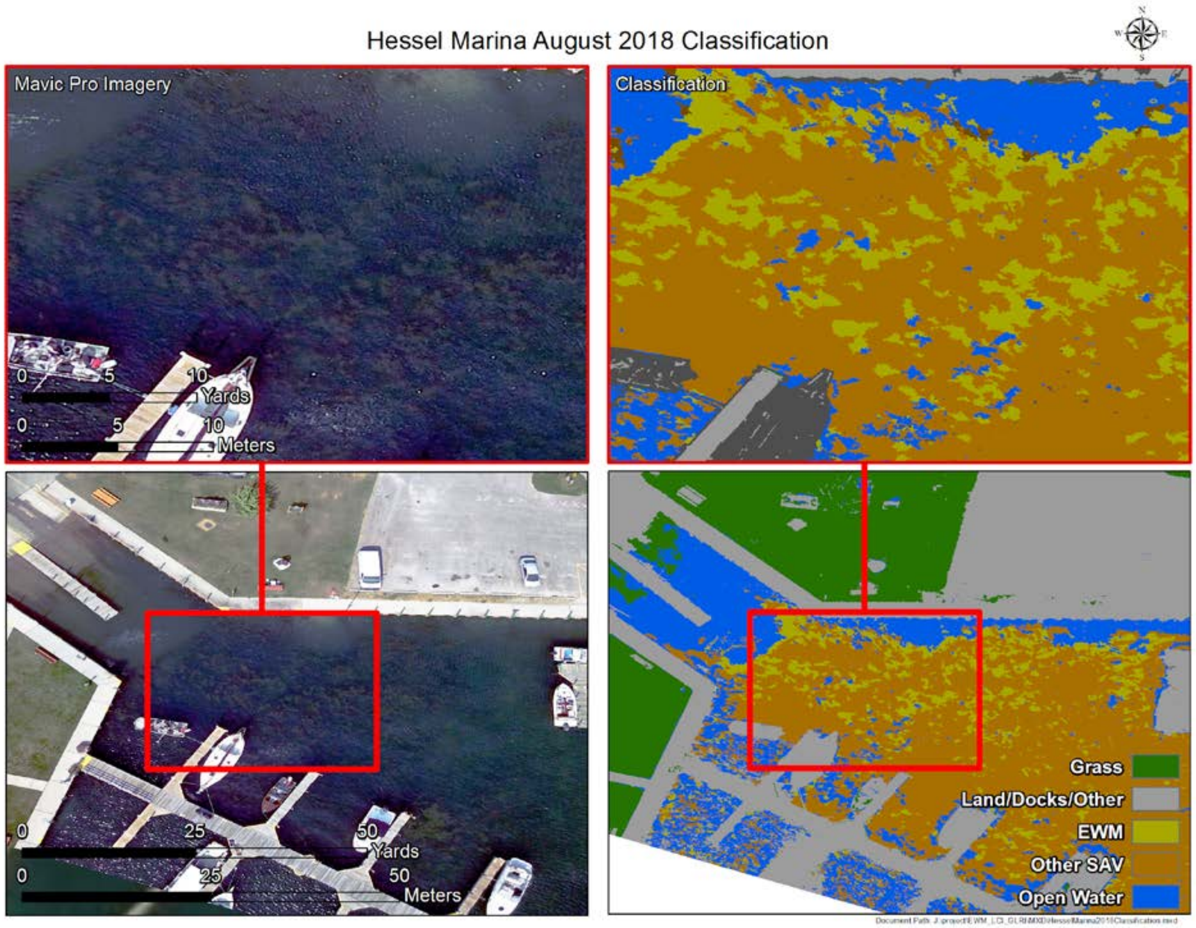


Figure 19: August 2018 UAS images and classification results of Hessel Marina one year after Mt fungus treatment. EWM appears lense dense, and within a matrix of other SAV.

Table 5 shows that based on classification of UAS imagery for Hessel Marina, EWM appears to have become less prominent from 2017 to 2018 (one year after treatment), with other SAV making up the largest area a year later. In 2017, EWM was 59.6% of the approximate Mt fungus treatment area, but was only 16.6% of that same area in 2018. Other SAV appears to make up the difference, along with a reduction in open water. While there is the potential for error in such classifications, these figures illustrate that within the limits of image analysis, the UAS imagery can help monitor changing EWM extent for this biocontrol treatment method.

Table 5: Comparison of 2017 vs. 2018 EWM extent within treatment area based on UAS imagery analysis.

Cover type	July, 2017	% of area	Aug., 2018	% of area
Open Water	1918.39	30.3%	566.96	9.0%
EWM	3769.85	59.6%	1041.906	16.6%
Other SAV	109.10	1.7%	4175.084	66.4%
Cars/Boats/Other	529.24	8.4%	501.89	8.0%
	6326.59		6285.84	

Area units are in ft^2

4.3.2 Task 3b. Field surveys, including collecting ecological and macrophyte community data

This project included assessments of aquatic vegetation, environmental characteristics, and ecological processes (i.e., water chemistry, phytoplankton chlorophyll-a, water depth, light transmission, etc.) to gain data needed to understand EWM, the Mt fungus treatment, and provide information to inform the remote sensing-based monitoring. This included bay-scale aquatic vegetation surveying by EnviroScience, Inc., continuing a time series of monitoring data that they initiated in 2013 for LCI. Complementary sampling by Michigan Technological University was performed at a spatial scale that could be easily related to the spectral profile and UAS imagery data collected to identify plants using remote sensing tools and to obtain more detailed information about biomass, water quality, and treatment sites. These methods were described in the QAPP, with some changes informed by practical field experience to adjust the spatial distribution of our sampling from that described in the QAPP.

4.3.2.1 EnviroScience vegetation surveys

The LCWC has contracted the environmental consulting firm EnviroScience Inc. to monitor aquatic vegetation in inner waterways of the Les Cheneaux Islands on an annual basis since 2007. Continuation of this monitoring program, including point-intercept and aquatic vegetation assessment sites (AVAS) surveys, was funded in part by this project for 2016-2018. The methods and results for the EnviroScience annual survey work are summarized here; annual reports providing greater detail are available on the LCWC website (http://www.lescheneauxwatershed.org/library/nuisance-species/aquatic-vegetation-and-weevil-surveys).

Surveying was performed using the Michigan DEQ guidance contained in "Standard Procedures for Surveying Aquatic Plants" (available at https://www.michigan.gov/documents/deq/wrd-illm-surveyprocedure_445615_7.pdf). For consistency, the same survey areas have been monitored annually around the same time of the year since 2013. Plant community data were collected through visual and rake tow surveys along evenly-spaced transects of the littoral zone. In each of these transect zones, the presence and relative density of each aquatic plant species was determined and the information was recorded on the Standard Aquatic Vegetation Assessment Site Species Density Sheet developed by the State of Michigan. Visual and rake surveys were performed at each site until no new species were encountered and the biologists conducting the survey were confident that adequate information had been obtained to estimate the density of each species encountered. Species of unknown identity were placed in a sample bag, appropriately labeled, and identified using taxonomic keys at the completion of the survey. The approximate percentage of cumulative cover (%CC) was reported as cover codes A, B, C, and D to describe the approximate coverage of each plant between each transect and within each AVAS.

Point-intercept (PI) surveys were conducted annually in the LCI areas of Cedarville and Sheppards Bays
following the methods outlined in “Point Intercept and Line Intercept Methods for Aquatic Plant Management” (Madsen, 1999). This survey method was chosen based on the relatively shallow depths and larger areas of both bays. A grid of evenly-spaced point intercepts was created using GPS technology, and the surveyors navigated to each point along the grid. At each PI, the presence and relative density of each aquatic plant species was determined based on a single rake tow. Once the rake was retrieved from a point, each species found on the rake was identified and assigned a density code for rake cover similar to the AVAS method. Species of questionable identity were identified at the completion of the survey.

The EnviroScience survey areas included the main project areas of Cedarville Bay and Hessel Harbor in addition to several additional sites. In Cedarville Bay, EWM density and cover as measured by the point-intercept surveys decreased fairly consistently from the alarming peak growth seen in 2012 through 2017, with EWM present at 51, 44, 28, 11, and 14 out of 146-148 survey points in 2013-2017 respectively (Figure 20). The dominant species observed in Cedarville Bay beginning in 2013 were consistently eelgrass and *Chara*. In contrast, the Cedarville Bay AVAS transect data, which covers only the westernmost portion of the point-intercept survey area, indicated a significant increase in EWM cover in the area from the public boat launch to the FDS marina, from 1% cumulative cover in 2014 to 40% CC in 2017.

The Hessel Harbor survey area was consistently dominated by *Chara*, with EWM increasing slightly from 2015 (1.0% of cumulative cover) to 2017 (5.5% CC) but remaining at a low density compared to 2013-14 (17-40% CC). A new invasive species, curlyleaf pondweed, was identified at Hessel for the first time in 2016 but not seen in 2017. Similar patterns of EWM cover declining steeply from 2012 to 2015 and then remaining relatively low were observed for all of the other EnviroScience-surveyed areas, though small increases in cover were observed from 2016 to 2017 in 16 of the 18 areas surveyed in both years.

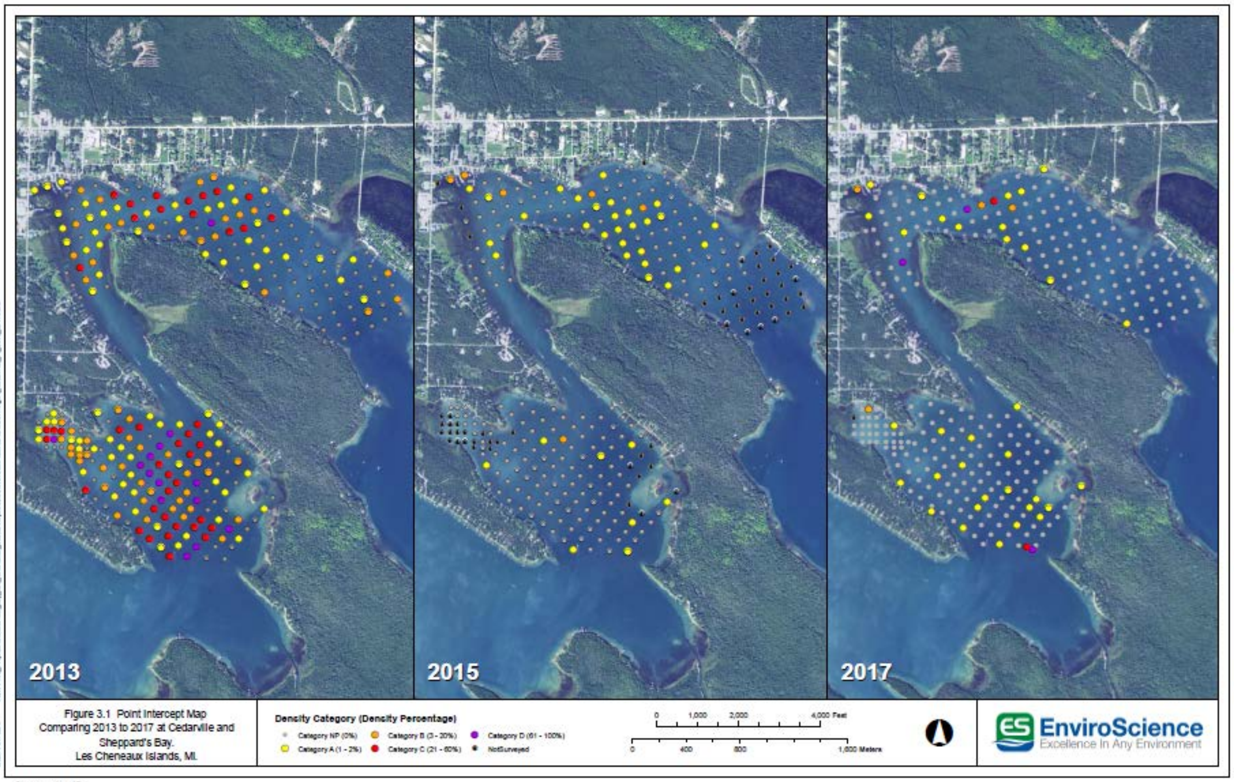


Figure 20: Point intercept survey map comparing 2013, 2015 and 2017 in Cedarville and Sheppard's Bays.

New survey points were added within the experimental Mt application areas in 2017. The EnviroScience crew, surveying August 22-24, 2017, approximately 1 month after the Mt treatment, did not observe signs of damage to the stems or leaflets in the treated areas. The four Hessel Harbor points were scored a B (3%-20%) in EWM density, and the four Cedarville Bay points scored 'no EWM observed', A (1-2%), B, and C (21%-60%) at one point each. Of two points at Breezeswept, no EWM was observed at one point and EWM density at the other point was scored a B. The last two locations were within the boat slips of Cedarville Marina and both were scored an A .

The 2018 EnviroScience survey work indicated that EWM continued its slow increase in abundance along the shorelines of Islington Channel, Snows Channel and Sheppards Bay, while desirable, low-growing native species continued to dominate Cedarville Bay and central Sheppard's Bay. The second-year evaluation of the MT sites revealed mixed results. The milfoil appeared healthy and green during the August 2018 survey at all the locations, but density changes were noted. Two of the four treatment sites decreased in Hessel Harbor. A third site (HHMt4) may have also decreased but a yacht obstructed the survey. Five of the eight treatment sites in Cedarville Bay increased in density, while two decreased (Table 6).

Table 6. EWM density scores assigned by EnviroScience to Mt treatment locations shortly after treatment (August 2017) and 13 months after treatment (August 2018).

Scores are N (no EWM observed), A (1-2% density), B (3-20% density), C (21-60% density) or D (>60% density). HH = Hessel Harbor, CB = Cedarville Bay, BS = Breezeswept. See maps in Appendices B and C for exact sampling locations.

	HHMt1	HHMt2	HHMt3	HHMt4	CBMt5	CBMt6	CBMt7	CBMt8	BSMt9	BSMt 10	CBMt 11	CBMt 12
2017	B	B	B	B	N	C	B	A	N	B	A	A
2018	B	A	A	N?	A	N	B	C	B	B	B	B

4.3.2.2 Michigan Tech vegetation and water sampling

For our vegetation data collection, instead of using a line-transect method as originally planned, we modified our Michigan Tech sampling plan to characterize set points that could be directly matched in space with marked locations in aerial imagery, in the process developing a robust sampling protocol that can be applied to any aquatic monitoring program integrating point samples and remotely collected imagery in aquatic environments.

At each sampling site on each date, we used marker buoys for areas where vegetation, chemistry, and imagery data were collected. Between two and four marker buoys were deployed at points of interest in the area to be sampled using UAS-based imagery (Figure 21 shows these marker buoys as seen from the side of the boat, and from above in a UAS image). We collected a GPS location for each buoy using a Trimble GeoExplorer GPS unit running in “code phase”, meaning it was collecting with accuracy in the typical range of 50 cm to 1 m (1.6 to 3.3 feet). As previously described we collected boatside spectral profiles of submerged aquatic vegetation using a spectroradiometer, either an ASD FieldSpec3 or the LPR that using Ocean Optics radiometer sensors. Aerial imagery was collected via UAS. At each site for one these marker buoy locations, we also sampled water chemistry and physical characteristics (light extinction, Secchi depth, water depth conductivity, temperature, pH, water samples for dissolved and total nutrients, underwater and surface photos) following methods detailed in the approved QAPP.

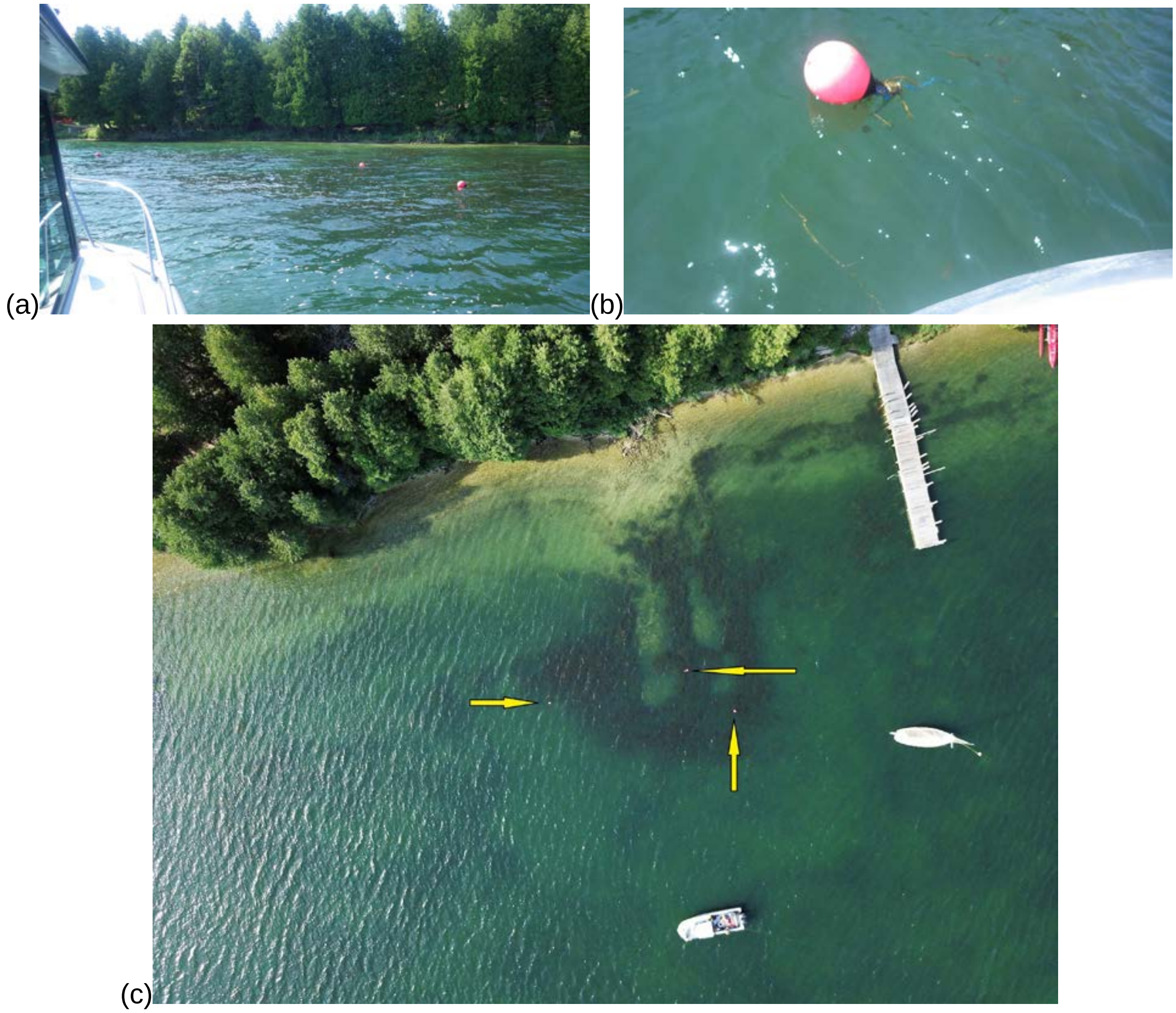


Figure 21: Marker buoys deployed for an example sampling site, Howells Dock. (a) Marker buoys visible from the sampling boat, (b) close-up to one of the marker buoys, (c) the same buoys visible in a UAS image of Howells Dock (yellow arrows point to the three buoys placed temporarily for this site).

Following collection of physical and chemical characteristics and all boatside and UAS-based spectral data, we characterized the macrophyte assemblage surrounding each marker buoy using three approaches: 1. Visual observations of percent cover of different macrophyte species in a 3-m (10 foot) radius and depth below water surface facing forward, port and starboard from the bow of the boat, which was tied to the marker buoy for sampling; 2. Relative abundance of macrophytes using three sampling rake tosses forward, port and starboard from the bow and classified using aquatic macrophyte assessment site (AMAS) procedures recommended by the Michigan Department of Environmental Quality (MDEQ 2005); 3. Twist samples for standing crop estimates collected forward, port and starboard from the bow by lowering a 16.5 cm (6.5") diameter double sided rake vertically to the lake bottom (Johnson and Newman 2011) and spinning one revolution to collect a 0.214 m^2 (2.3 ft^2) sample of macrophytes. Biomass samples were sorted, identified and analyzed following procedures detailed in the QAPP.

This sampling revealed that EWM comprised 15-80% of the macrophyte assemblage sampled using visual estimates on most sampling dates (Figure 22), which is unsurprising as these sampling sites were selected to focus on collection of UAS imagery to determine the feasibility of classifying and mapping EWM. The native macrophytes were diverse across all sites and dates. The greatest species richness was observed at the three marina sites (Breezeswept, Hessel Marina, FDS), which were the sites of greatest boat traffic and disturbance (boat props and mechanical harvesting) (Table 7). All macrophyte samples have been processed to date.

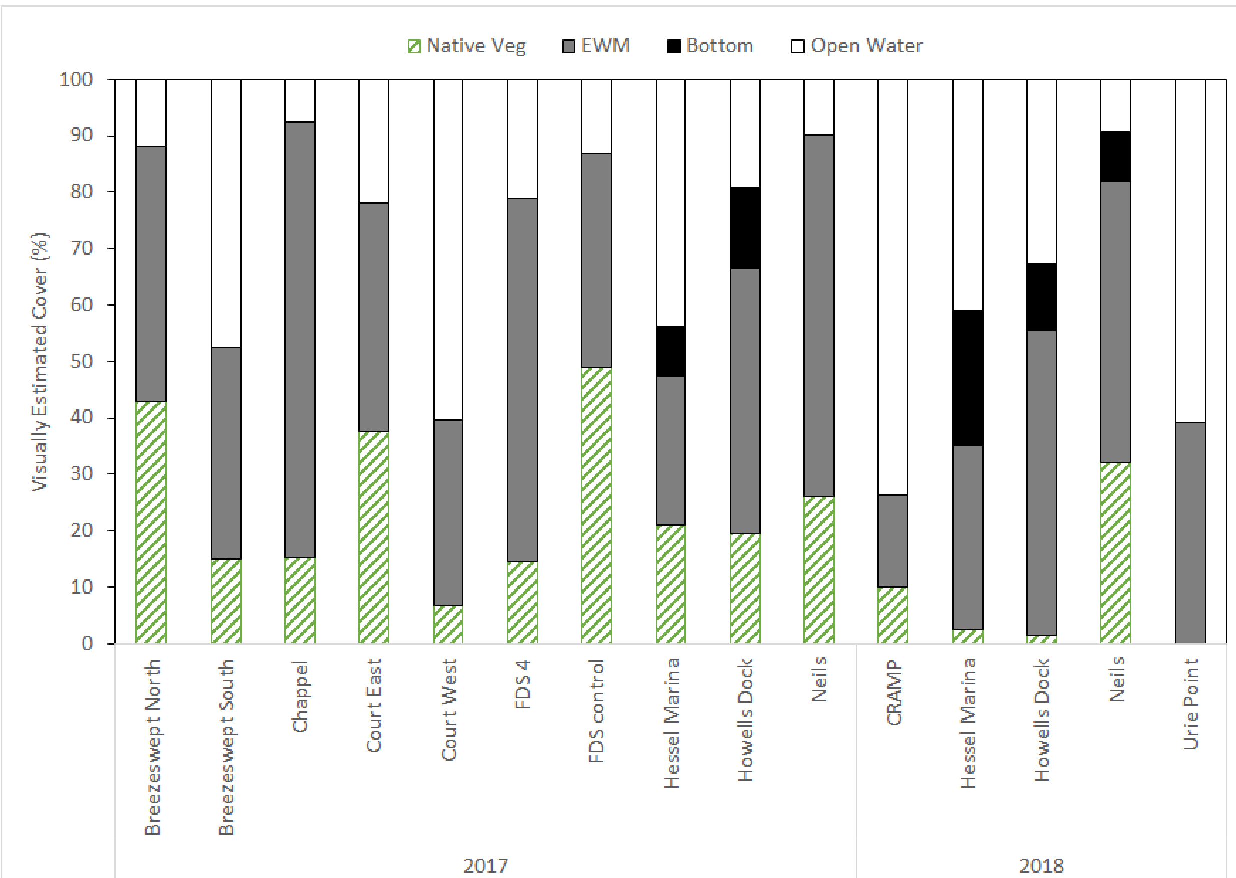


Figure 22: Visual estimates of cover at all sampling sites in Aug 2017 and 2018

Table 7: Macrophyte species observed across all sites and dates using rake toss, twist and visual estimate methods.

			SITES										
Group	Common Name	Scientific Name	Breeze-swept	Chappel	Court Dock	Court East	Court West	CRAMP	FDS	Hessel Marina	Howells Dock	Neil	Urie Point
Aquatic Mosses	Aquatic Moss	Several genra, especially *Drepanocladus* and *Fontinalis*							x				
Arrowheads	Arum-leaved arrowhead	*Sagittaria cuneata*										x	
Bladderworts	Common Bladderwort	*Utricularia macrorhiza*							x				
Bur-reeds	Floating Bur-reed	*Sparganium fluctuans*	x										
Chara	Small Nitella	*Nitella tenuissima*	x										
Coontail	Coontail	*Ceratophyllum demersum*	x		x	x	x	x	x	x	x		
Naiads	Slender Naiad	*Najas flexilis*		x	x	x			x	x	x	x	x
Pondweeds	Algal-leaved Pondweed	*Potamogeton confervoides*	x		x	x			x				
Pondweeds	Clasping-leaf Pondweed	*Potamogeton richardsonii*	x	x		x	x			x	x		
Pondweeds	Curly-leaf Pondweed	*Potamogeton crispus*	x		x	x	x		x	x			
Pondweeds	Fern Pondweed	*Potamogeton robbinsii*							x		x		
Pondweeds	Flatstem Pondweed	*Potamogeton zosteriformis*	x	x	x	x	x	x	x	x	x		
Pondweeds	Floating-leaf Pondweed	*Potamogeton natans*	x										
Pondweeds	Fries' pondweed	*Potamogeton friesii*						x		x		x	
Pondweeds	Large-leaf Pondweed	*Potamogeton amplifolius*	x										
Pondweeds	Leafy Pondweed	*Potamogeton foliosus*				x			x				
Pondweeds	Sago Pondweed	*Stuckenia pectinata*	x									x	
Pondweeds	Sheathed Pondweed	*Stuckenia vaginata*							x	x			
Pondweeds	Small Pondweed	*Potamogeton pusillus spp.*	x		x	x	x		x	x		x	
Pondweeds	Variable Pondweed	*Potamogeton gramineus*	x		x								
Pondweeds	Whitestem Pondweed	*Potamogeton praelongus*							x				
Quillworts	Lake Quillwort	*Isoetes lacustris*		x						x		x	
Stoneworts	Chara	*Chara* spp.	x	x			x		x	x	x	x	x
Water Celery	Eel Grass/Water Celery	*Vallisneria americana*	x			x			x	x	x	x	x
Water Crowfoot	White Water Crowfoot	*Ranunculas aquatilis*	x		x				x	x		x	
Water Marigold	Water Marigold	*Bidens becki*	x		x	x			x	x			
Water Stargrass	Water Stargrass	*Heteranthera dubia*	x			x	x		x	x	x	x	
Watermilfoils	Eurasian Watermilfoil	*Myriophyllum spicatum*	x	x	x	x	x	x	x	x	x	x	x
Watermilfoils	Northern Watermilfoil	*Myiophyllum sibiricum*	x	x	x				x	x	x	x	
Watermilfoils	Various-leaved Watermilfoil	*Myriophyllum heterophyllum*	x		x				x		x		
Waterweeds	Elodea	*Elodea canadensis*	x	x	x	x	x	x	x	x	x	x	

4.4 Task 4: Development/improvement of Mt biocontrol methods

The GLRI "Arresting the spread of Eurasian watermilfoil in Lake Superior" grant started a centralized, web-based clearinghouse of reliable information on EWM control and management. This information is available at http://www.mtri.org/eurasian_watermilfoil.html and includes information on biology, invasive properties and ecological impacts, development of mapping and modeling tools, spread, and further web resources. Information from Les Cheneaux Islands Eurasian Watermilfoil Control grant was used to expand the previous grant's output to include vetted, up-to-date information on biocontrol options, necessary inputs, and limitations. This leveraging of previous work and extending it through work took advantage of this project taking place in Les Cheneaux Islands, where an active community represented by the Les Cheneaux Watershed Council has been working to implement effective, safe, and economical biocontrol programs.

LCWC has been posting information on its Mt biocontrol work to serve as information for updated best management practices for use of this treatment method. For examples, please see http://lescheneauxwatershed.org/projects/mycoleptodiscus-terrestris and especially their final report at http://www.lescheneauxwatershed.org/library/nuisance-species/eurasian-watermilfoil/lcwc-ewm-research/310-wc6-use-of-mycoleptodiscus-terrestris-as-a-mycoherbicide-for-myriophyllum-spicatum-eurasian-watermilfoil-management-in-the-open-water-system-of-the-les-cheneaux-islands-michigan (Smith et al. 2018a). The LCWC final report serves as the main summary of the Mt treatment methods and impacts, and are described in further detail below.

The Smith et al. 2018a LCWC report documents the results of the Mt treatment at 25, 30, 45, and 70 days after treatment (DAT) with quantitative results for the Hessel Marina site, as compared to untreated control sites at Howells Dock and Point Urie (see Figure 5 for locations). Results have been posted to the LCWC site and linked to from the project information web page at http://www.mtri.org/ewmlci.html. The degree of Mt infectivity in EWM was quantified using the change in EWM biomass over time. Biomass change was calculated as mg of EWM wet weight per cm of stem length. A grapnel hook was used for collecting plant samples. Wet weights were recorded within 24 hours, and dry weights were recorded after a drying procedure that started with 72-80 hours of air drying followed by oven drying at 80℃ (176℉) for 12 hours. The weight and dry weights were recorded in both weight per inch of stem and weight in mg per cm of stem.

The main result seen was that EWM biomass decreased at the Hessel Marina treatment site in the weeks after treatment, but stayed constant or increased at the two untreated control sites in the days and weeks after treatment. These results were similar to initial field trials in 2014 when the USDA was able to produce the Mt fungus. Between 25 and 30 DAT, a downward trend in EWM biomass at the Hessel Marina site vs. an increasing trend at the untreated Point Urie site could be identified (see Figure 23, which is Figure 1 from the Smith et al. 2018a report). Hessel Marina saw an almost 75% reduction in biomass 70 DAT when compared to the Point Urie and Howells Dock sites. These results were similar to the 2014 Mt trial in the LCI where an 85% biomass reduction was seen. The LCWC noted that water temperature dropped seven degrees F during the 70 DAT period but biomass loss continued. Smith et al. 2018a concluded that "Observations from these two open water trials indicate that Mt can reproducibly and significantly reduce EWM biomass in LCI waters, even when the water temperature is less than optimum.

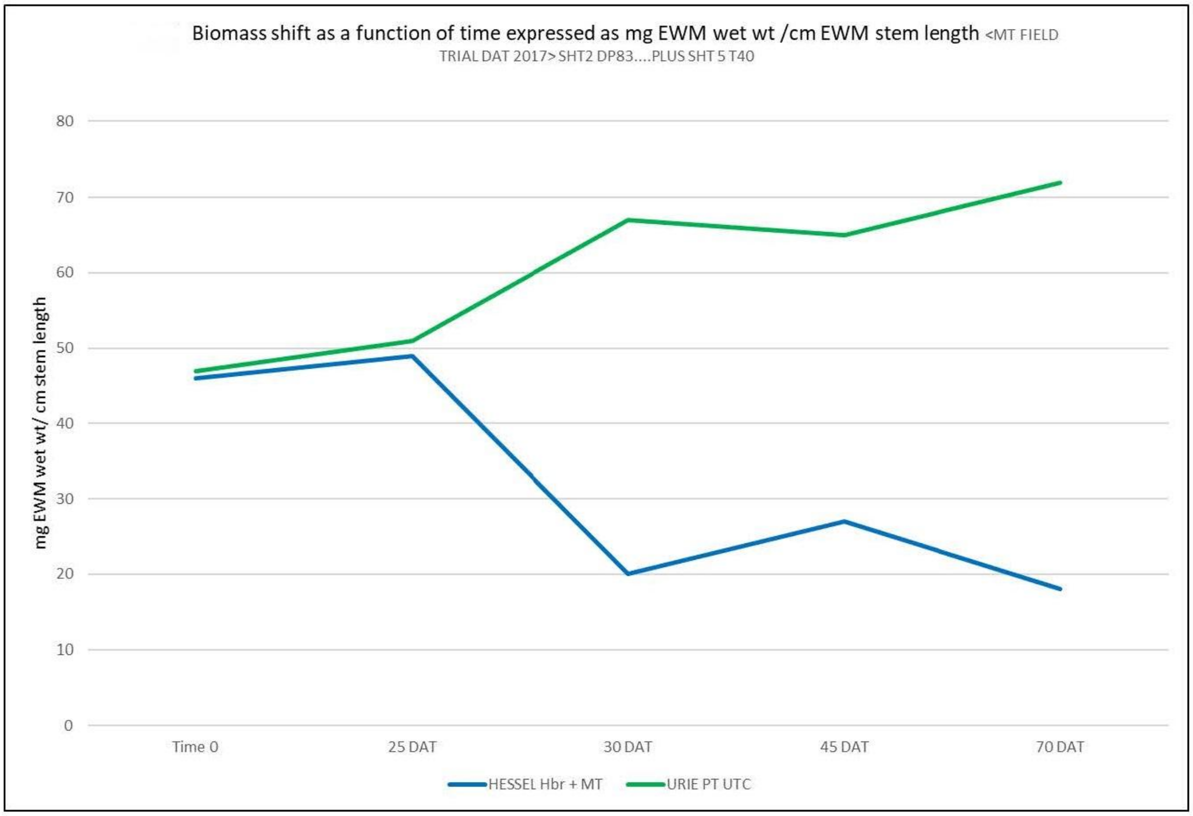


Figure 23: Change in biomass at treated Hessel Marina site vs. untreated Urie Point site from time of treatment to 70 DAT; biomass declined at the treated site vs. the untreated site.

In the Smith et al. 2018a report, the LCWC authors briefly note that EWM growth appeared less vigorous one year after treatment. EWM biomass at Hessel Marina was less than one-half of the biomass vs. the untreated Urie Point area. No obvious impacts could be seen on non-target aquatic plants. The LCWC partners followed up this initial evaluation with a more detailed report, Smith et al. 2018b, entitled "Residual effect of *Mycoleptodiscus terrestris* (Mt) on *Myriophyllum spicatum* (Eurasian watermilfoil) one year post treatment", dated October 31, 2018. They describe EWM growth 410 DAT (one year and 45 days after the July 2017 treatment) as showing a residual effect that delayed EWM growth vigor in the early part of the 2018 growing season (Figure 24). In 2018, EWM density was at a level similar to the low density seen 70 DAT in 2017. The Hessel Marina site also saw significant growth of the native plants Coontail (*Ceratophyllum demersum*) and flatstem pondweed (*Potamogeton zosteriformis*), likely forming the "Other SAV" areas in the August 2018 UAS image and classification shown in Figure 19, whereas Urie Point was an EWM monoculture.

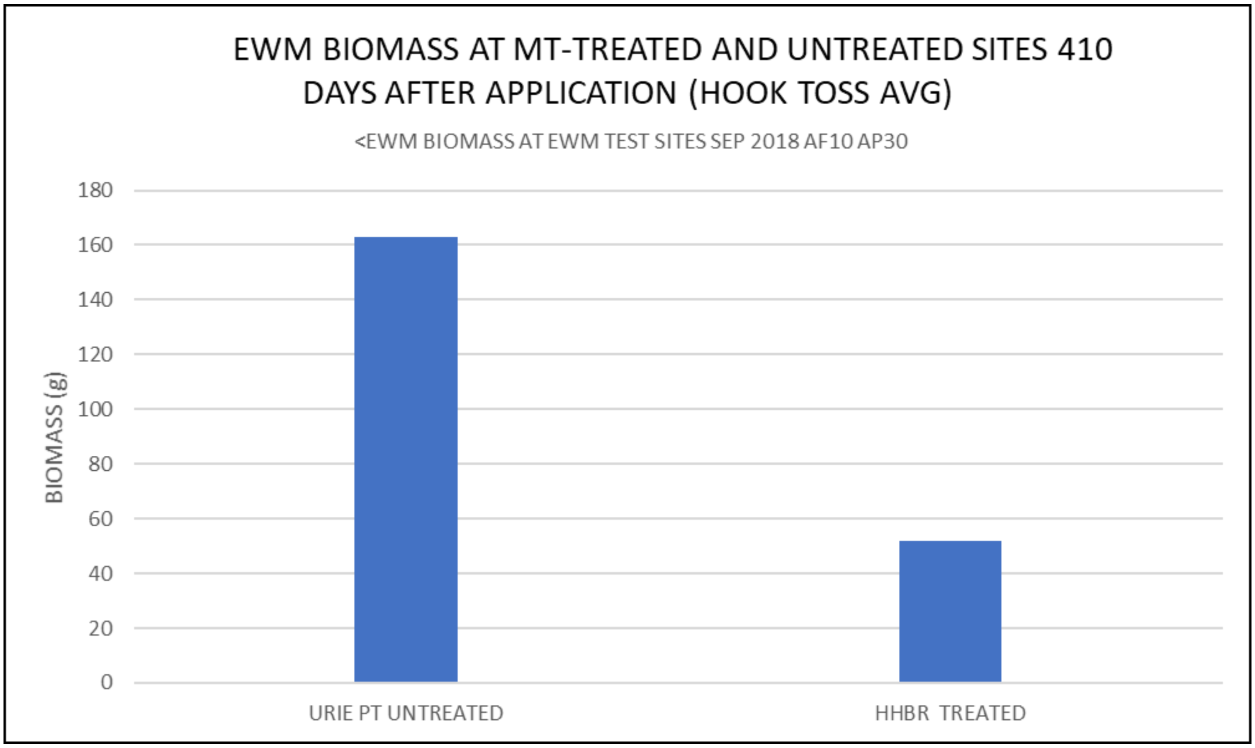


Figure 24: At 410 days after treatment, EWM biomass at the Hessel Marina (aka HHBR) treated site was less than ½ of the EWM biomass at the untreated Urie Point reference site, indicated a potential residual effect of Mt treatment.

Independent sampling by Michigan Tech scientists prior to and one year following treatment with Mt fungus in support of UAV-based monitoring suggest that EWM persisted at the treatment sites at similar amounts as in untreated control sites. EWM comprised 16.5% of the visual cover at CRAMP one year following treatment, with no comparable pretreatment data collected. At Hessel Marina, EWM visual cover increased slightly from 26.3% to 33.6% one year following treatment within the observation areas near sampling points (note that the EWM percent cover shown in Figure 19 covers a larger area than these visual sampling locations, however). EWM cover increased 7% but decreased 14% at two different control sites, suggesting the magnitude of change observed in Hessel Marina one year post treatment could be due to natural variations in EWM populations (Figure 25) rather than necessarily being due to treatment. Similar changes in EWM abundance before and after treatment were detected using rake toss and AMAS surveys, with EWM increasing in Hessel Marina between August 2017 and 2017, and both increasing and decreasing at the control sites (Figure 26).

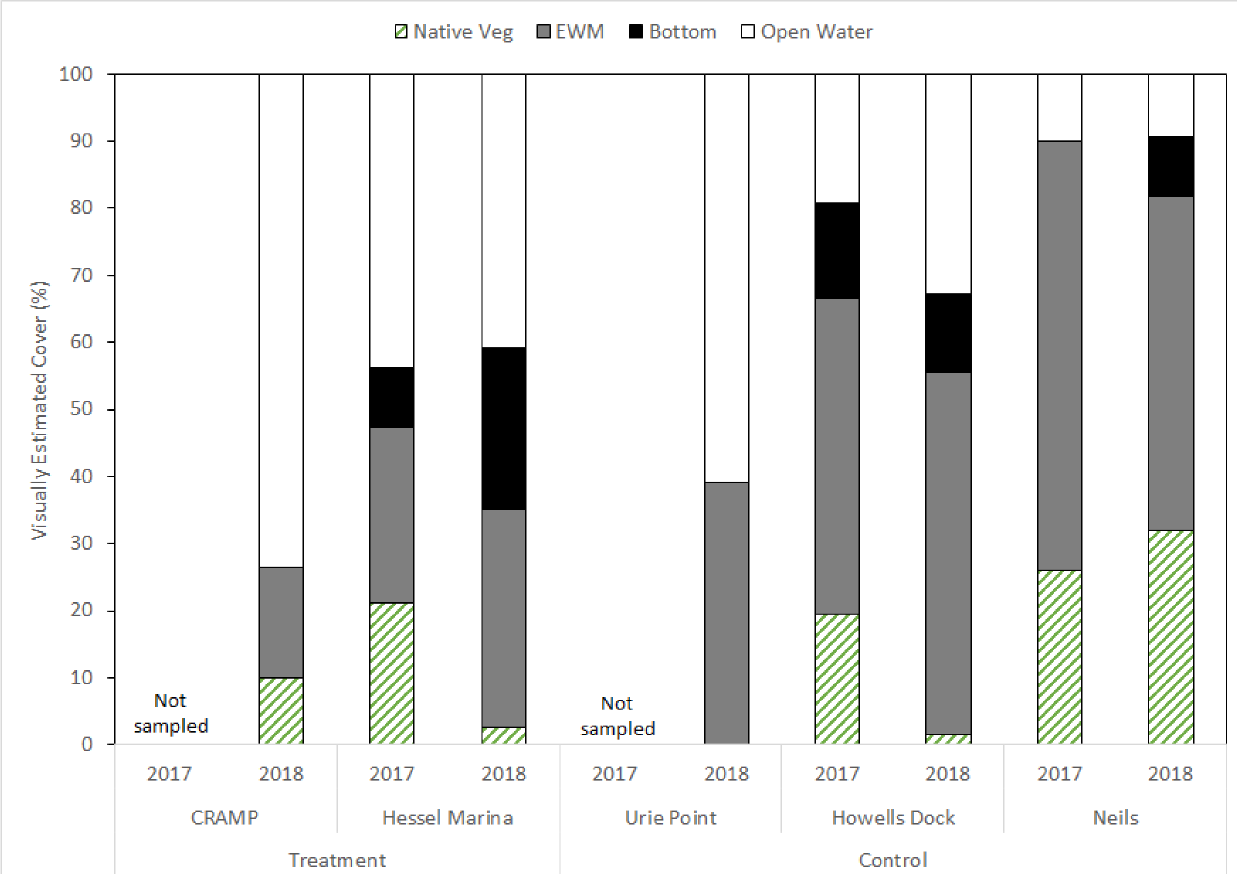


Figure 25: Visual estimates of cover at the treatment and control sites in August 2017 and 2018.

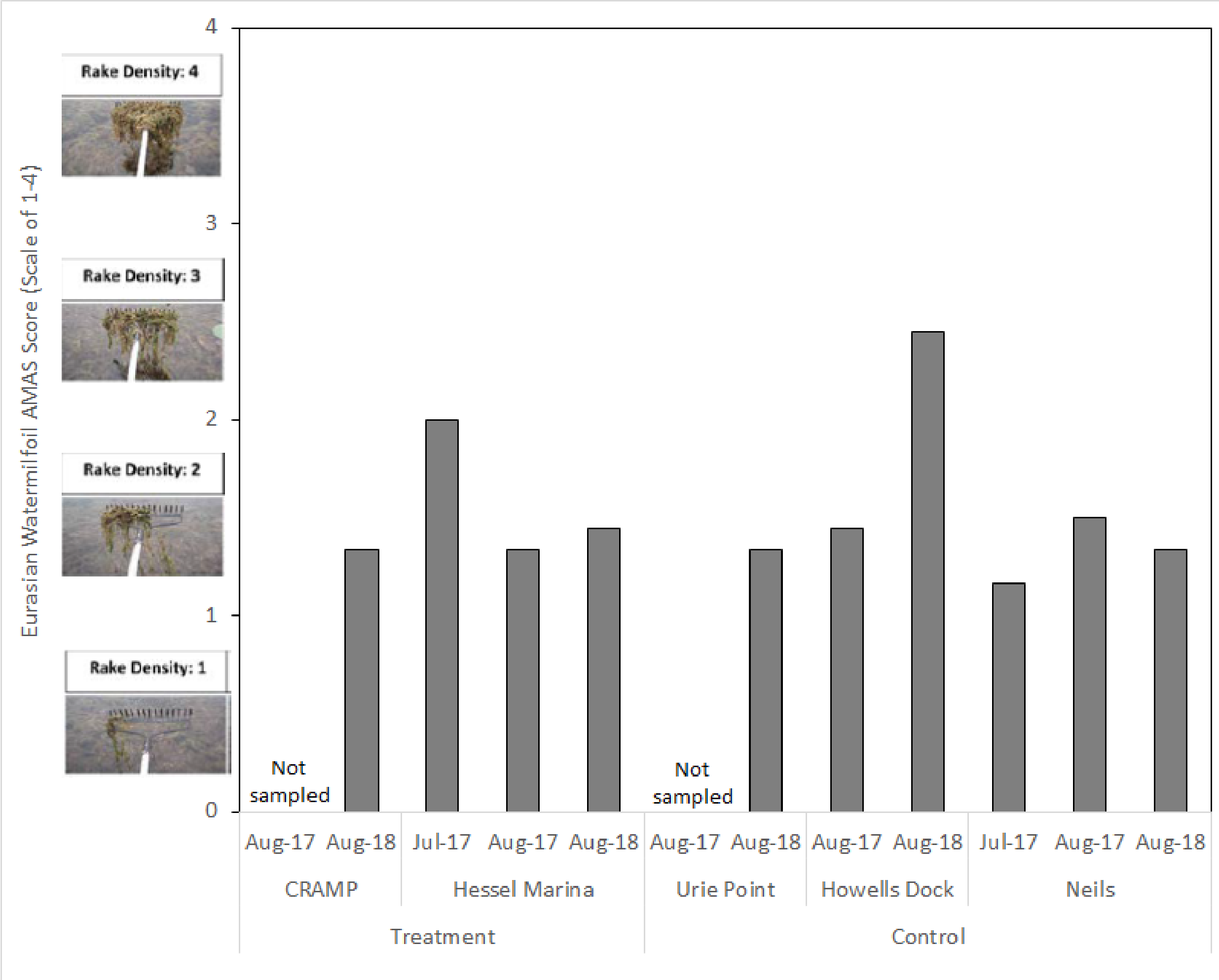


Figure 26: Estimates of EWM abundance using rake tosses and AMAS surveys at the treatment and control sites in July, August 2017 and August 2018.

4.5 Task 5: Reporting and Communication of Results

The project has included an active outreach program focused on communicating results to local stakeholders and the scientific community. In 2016, 2017, and 2018, results of the project were shared with the Les Cheneaux Watershed Council at their annual meeting, and through the Council newsletter. Additionally, PI Brooks presented to the LCWC annual meeting in person in July 5th, 2018, and answered questions from community members. PI Brooks and Co-I attended the community Frogfest on July 7th, 2018, and had a booth present where community members, including children, had the opportunity to ask questions of project scientists, look at the UAS and cameras used to collect data, see a UAS flight demonstration, and interact with a display with EWM and other aquatic vegetation in a fish tank. Figure 27 shows Dr. Marcarelli engaging with Frogfest attendees about the project, and Figure 28 shows Mr. Brooks discussing UAS-based imaging. The LCWC estimated the between 390 and 440 people attended Frogfest in 2018.

Figure 27: Dr. Marcarelli engaging with community members at the July 2018 Frogfest, helping explain the project and share information on submerged aquatic vegetation.

Figure 28: Mr. Brooks explaining how UAS can be used to collect EWM extent data during the 2018 LCI community Frogfest.

In addition to updating the EWM resource page from the “Arresting the spread…” GLRI project (http://www.mtri.org/eurasian_watermilfoil.html), a dedicated project web page was created and maintained at http://www.mtri.org/ewmlci.html. This enabled anyone interested in the project to get a rapid overview of the project and a rotating set of representative field photos and aerial images helping show what was going on with the project. The LCWC also shared information about the project through its webpage, including a project overview at http://www.lescheneauxwatershed.org/library/grants/lci-eurasian-watermilfoil-control-glri-2016-17 and information about the previous vegetation and weevil surveys (http://www.lescheneauxwatershed.org/library/nuisance-species/aquatic-vegetation-and-weevil-surveys).

Also, Mark Clymer of the LCWC recently completed an update to EWM best management practices, entitled “Best Management Practices Enhancement: Les Cheneaux Islands Eurasian Watermilfoil Control”. After five seasons of Mt field work since 2013 by the LCWC, the updated BMPs describe Mt fermentation, transportation, application, safety, and permitting practices. This is being posted to the LCWC website; the main points are shown below as Table 8.

Table 8: Main points on Mt fungus treatment Best Management Practices, as updated through this project.

7. Mt BMP Summary
    a. Fermentation process and formulation have not changed since the Mt Patent was registered in 2003.
        i. Patent available at: http://pdfpiw.uspto.gov/.piw?docid=06569807&PageNum=1&&IDKey=4D26889BBEB4&HomeUrl=http://patft.uspto.gov/netahtml/PTO/patimg.htm
    b. Mt can be stored safely at 4C for up to one week. Further refinement of the Mt formulation's stability will be necessary to bring an Mt product to market.
    c. Sheer issues were successfully addressed prior to this grant project by previous LCWC research and development. Future refinement of the LCWC proprietary application equipment is not necessary, except as may be competitively desired to apply larger volumes at a faster rate.
    d. Used at full strength directly from the fermentor, Mt has been shown to be effective when applied at a rate of 40 gallons per acre.
    e. Optimally, Mt will be applied when water temperatures are at or close to 22C.
    f. A consistent Mt efficacy rate of over 85% has so far been demonstrated on ¼ acre open water, northern climate areas. Further demonstration projects on larger acreages are warranted based on this research.
    g. A drift effect was recorded in the 2014 field work, but there were not enough data points to create a BMP.
    h. Similarly, a carry-over effect was observed during 2018 monitoring, but samples collected were not dried & weighed due to the mix of EWM with other aquatic vegetation, yet this in itself showed signs of a newfound ability to compete with Mt 1 year after treatment. More research is needed in this area.
    i. The safety of Mt was born out by the USDA genetic testing providing a positive correlation between the toxicity and pathogenicity data collected by LCWC, and Ecoscience data on file with EPA.
    j. Mt does not grow at mammalian temperatures (37C).
    k. This GLRI grant has supported efforts in applied research & application development of Mt as an effective Biopesticide for use in EWM control a step closer to commercial scale-up and EPA Registration.

Two project signs were also erected in the project area, near the primary project locations - one near the Hessel Marina boat ramp, and other one near the community boat ramp in Cedarville. Each sign provides project information, includes the GLRI logo, and credits the Great Lakes Restoration Initiative and EPA for funding. Figure 29 shows PI Brooks standing by the sign in the Hessel Marina that was right by the main treatment location.

Figure 29: PI Brooks standing near the project information sign placed in Hessel Marina right by the primary Mt treatment site.

Robert Smith from the LCWC involved high schools students from the Les Cheneaux Community Schools in understand EWM management in the area. In June of 2018, he presented to Cedarville High School science and Environmental Studies classes on the project and EWM management to about 24 students per class (about 48 total). Please note that each year-class at our HS is comprised of 25-30 students. The students then went on a field trip to the Cedarville boat ramp (CRAMP site) to see one of the active areas of EWM management. Mr. Smith made second presentation to six professors and eight graduate students at the University of Michigan Biological Station at Douglas Lake the evening of 24 July, 2018. He made a third presentation that summer on the project to the general public at theLes Cheneaux library in Cedarville on the evening of 26 July, 2018 which was attended by about 28 community members.

PI Brooks presented on the project at the International Association of Great Lakes Research (IAGLR) Annual Conferences in 2017 (Detroit) and 2018 (Scarborough/Toronto), as well as the 2018 Society for Freshwater Science Conference (Detroit). Mr. Brooks took the opportunity to share project results at other fortuitous outreach opportunities. He shared information on SAV mapping with UAS through a webinar hosted by the Electric Power Research Institute (EPRI) at their February, 2018 Cooling Water Intake online meeting. At the 2017 Michigan Drone Day hosted by Eastern Michigan University, he featured the project work as one of eight UAV-enabled projects that he has worked on to help promote advanced technology implementation in Michigan and beyond. At the Ecological Society of America (ESA) conference in Ft. Lauderdale in August of 2016, he shared project plans and initial results on how remote sensing could help with SAV monitoring and management. An article about this and a colleague's Phragmites project was published in the Great Lakes Echo ("Fighting invaders with drones and fungi" - http://greatlakesecho.org/2016/09/30/fighting-invaders-with-drones-and-fungi/) which was shared over 90 times. Dr. Marcarelli and her graduate students also presented on the project at appropriate science conferences.

Publications (Peer-Review):

Brooks, CN, Grimm, AG, Marcarelli, AM, Dobson, RJ. Multi-Scale Collection of Submerged Aquatic Vegetation Spectral Profiles for Eurasian Watermilfoil Detection. Submitted to and under review by the Journal of Applied Remote Sensing, December 2018.

Van Goethem, RR. Effects of invasive watermilfoil and seasonal dynamics on primary production in littoral zones of north-temperate lakes. Masters of Science Thesis, Michigan Technological University, Houghton MI. Submitted December 2018.

Presentations (Science Conferences):

- Brooks, C. N., Grimm, A. G., Huckins, C. J., Marcarelli, A. M., Van Goethem, R., Dobson, R. J., Annual Conference on Great Lakes Research, "*Evaluating the spread and control of Eurasian watermilfoil through remote sensing technologies*" International Association for Great Lakes Research, Guelph, ON, Canada. (June 2016).
- Brooks, C., Grimm, A., Huckins, C. J., Marcarelli, A. M. (Presenter & Author), Annual meeting, "*Development of a spectral-based algorithm for mapping and monitoring of Eurasian watermilfoil (Myriophyllum spicatum) in the Great Lakes region from an unmanned aerial vehicle platform*" Ecological Society of America, Ft Lauderdale, FL. (August 2016).
- Brooks, C. N., Grimm, A. G., Huckins, C. J., Marcarelli, A. M., Van Goethem, R., Dobson, R., Annual Conference on Great Lakes Research, "*Using Advanced Mapping Tools to Help Monitor Eurasian Watermilfoil for Improved Treatment Options*" International Association for Great Lakes Research, Detroit, MI. (May 2017).
- Brooks, C., Marcarelli, A. M., Grimm, A. G., Dobson, R. J., Huckins, C. J., Van Goethem, R., Smith, R., Clymer, M., Marion, N., Annual Meeting, "*ANALYZING EURASIAN WATERMILFOIL EXTENT AND TREATMENT EFFICACY USING UNMANNED AERIAL SYSTEM (UAS) MULTISPECTRAL IMAGERY*" Society for Freshwater Science, Detroit, MI. (May 2018).
- Brooks, C., Marcarelli, A. M., Grimm, A. G., Dobson, R. J., Huckins, C. J., Van Goethem, R., Smith, R., Clymer, M., Annual Conference on Great Lakes Research, "*Demonstrating Unmanned Aerial System multispectral analysis of Eurasian watermilfoil treatments*" International Association for Great Lakes Research, Toronto, Canada. (June 2018).
- Marcarelli, A. M., Huckins, C. J., Juneau, K., Brooks, C., Chimner, R. A., Hersch-Green, E., Meadows, G. A., Midwest Aquatic Plant Management Society 36th Annual Meeting, "*Integrated management of nonnative and hybrid Eurasian Watermilfoil in the Portage Waterway of the Upper Peninsula of Michigan*" Midwest Aquatic Plant Management Society, Grand Rapids, MI. (March 8, 2016).

- Van Goethem RR, Marcarelli AM, Huckins CJ, Juneau JJ. Legacy disturbance in a lake littoral zone: effects of mining residue on the composition of macrophyte communities. Society for Freshwater Science Annual Meeting, Raleigh NC. (June 2017).
- Van Goethem, R. (Presenter & Author), Marcarelli, A. M., Huckins, C. J., Annual Meeting, "*Effects of Invasive Macrophytes on Littoral Primary Producers in North Temperate Lakes*" Midwest Aquatic Plant Management Society, Cleveland, OH. (February 2018).
- Van Goethem, R. (Presenter & Author), Marcarelli, A. M., Huckins, C. J., Annual Meeting, "*EFFECTS OF INVASIVE MACROPHYTES ON LITTORAL PRIMARY PRODUCERS IN NORTH-TEMPERATE LAKES*" Society for Freshwater Science, Detroit, MI. (May 2018).

5. Conclusions

Cumulative results achieved

The main cumulative results achieved through this GLRI-sponsored project were three-fold:

1) Taking a relatively new treatment method using the native Mt fungus to the point of practical deployment in the Great Lakes.
2) Demonstrating how UAS-enabled sensing can provide quantitative mapping information that helps monitor treatment methods such as mechanical harvesting, DASH treatment, and Mt biocontrol.
3) Deployment of a robust field sampling protocol that provides the needed information to document changes in EWM extent.

All three of these have been documented here, presented to local community members and other stakeholders, presented at scientific conferences, and form the main information for one Master's thesis and one dissertation paper (with two more related dissertation papers planned). A close partnership with the Les Cheneaux Watershed Council meant that community engagement, local employment, and science outreach were all possible. The Mt fungus treatment resulted in lower Mt biomass in the weeks after treatment relative to two untreated control sites, and there may be residual effects of the treatment one year later.

For post-completion activities, these will focus on writing and submitting additional peer-reviewed papers, along with continuing to work with the LCWC on pursuing opportunities to treat larger areas with the Mt fungus. Dissertation papers focused on an EWM-specific mapping algorithm, and on application of this algorithm to EWM treatment monitoring, will be submitted by PI (and PhD candidate) Brooks in 2019. Michigan Tech and the LCWC are investigating possible funding sources to continue their partnership in expanding methods of practical EWM treatment and extending results to the Great Lakes community.

Acknowledgment:

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6. References

Becker, B.L., Lusch, D.P. and Qi, J., 2005. Identifying optimal spectral bands from in situ measurements of Great Lakes coastal wetlands using second-derivative analysis. Remote sensing of environment, 97(2), pp.238-248.

Becker, B.L., Lusch, D.P. and Qi, J., 2007. A classification-based assessment of the optimal spectral and spatial resolutions for Great Lakes coastal wetland imagery. Remote Sensing of Environment, 108(1), pp.111-120.

Briggs, R., 1991. Review of toxicology and product analysis data in support of an Experimental Use Permit (EUP) application of *Mycoleptodiscus terrestris*, submitted by Ecoscience Laboratories, Inc. for control of Eurasian Watermilfoil. Memorandum, September 13, 1991. US EPA Office of Pesticides and Toxic Substances.

Brooks, C., Grimm, A., Shuchman, R., Sayers, M., & Jessee, N. 2015. A satellite-based multi-temporal assessment of the extent of nuisance Cladophora and related submerged aquatic vegetation for the Laurentian Great Lakes. Remote Sensing of Environment, 157, 58-71.

Environment Canada and U.S. Environmental Protection Agency. 1999. State of the Great Lakes 1999. Canada and United States of America.

Huckins, C., Marcarelli, A., Brooks, C., Grimm, A., Dobson, R., and Van Goethem, R. 2018. Innovative and multifaceted control of invasive Eurasian and hybrid watermilfoil using integrative pest management principles. Final Project Report, August 29, 2018.

Johnson J. A., Newman, R. M. 2011. A comparison of two methods for sampling biomass of aquatic plants. Journal of Aquatic Plant Management 49:1-8.

Madsen, J. 1999. Point intercept and line intercept methods for aquatic plant management. Aquatic plant control technical note U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Michigan Department of Environmental Quality (MDEQ). 2005. Procedures for aquatic vegetation surveys. <https://www.michigan.gov/deq/0,4561,7-135-3313_3681_3710-81012--,00.html>

Nicholls, S. 2012. The 2012–2017 Michigan Tourism Strategic Plan. Lansing, MI, USA. [http://www.michigan.org/lib/files/Industry/Tourism_Strategic_Plan/Final_Plan_with_Appendices.pdf]

Shearer, J.F. 1994. Field test of first commercial formulation of Mycoleptodiscus terrestris (Gerd.) Ostazeski as a biocontrol for Eurasian Watermilfoil. Misc. Paper A-94-4. US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Shearer, J. F., Jackson, M. A. 2006. Liquid culturing of microsclerotia of Mycoleptodiscus terrestris, a potential biological control agent for the management of hydrilla. Biological Control, 38(3), 298-306.

Shuchman, R. A., Sayers, M. J., & Brooks, C. N. 2013. Mapping and monitoring the extent of submerged aquatic vegetation in the Laurentian Great Lakes with multi-scale satellite remote sensing. Journal of Great Lakes Research, 39, 78-89.

Smith, R. Clymer, M. Dunn, D. Myers, S. 2018a. Use of *Mycoleptodiscus terrestris* as a mycoherbicide for *Myriophyllum spicatum* (Eurasian watermilfoil) management in the open-water system of the Les Cheneaux Islands, MI. Les Cheneaux Watershed Council.

Smith, R. Clymer, M. Dunn, D. Myers, S. 2018b. Residual effect of *Mycoleptodiscus terrestris* (Mt) on *Myriophyllum spicatum* (Eurasian watermilfoil) one year post treatment.

Sokal, R.R. and Rohlf, F.J. 1995. Biometry: the principles of statistics in biological research. WH Freeman and Co, New York, NY.

Villa, P., Bresciani, M., Braga, F. and Bolpagni, R. 2014. Comparative assessment of broadband vegetation indices over aquatic vegetation. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 7(7), pp.3117-3127.