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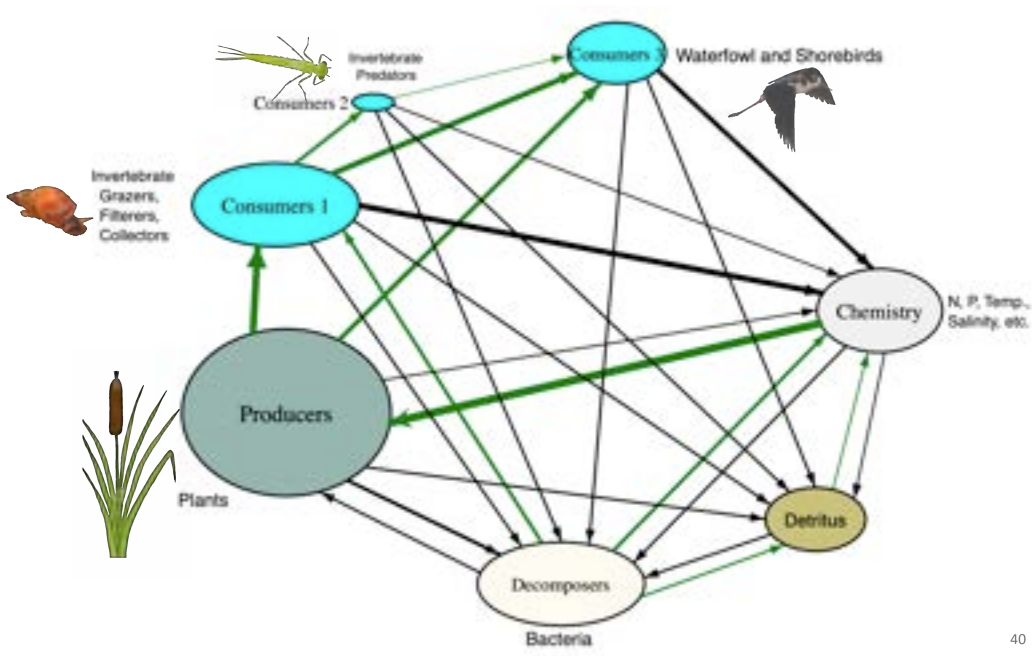
Ecology and Food Web Dynamics of an Effluent Dominated Wetland, Great Salt Lake, UT



Progress Report

To
North Davis Sewer District
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December 10, 2020

Summary

North Davis Sewer District's (NDSD) wastewater effluent provides on average 20 to 22 million gallons per day of treated wastewater to the northeastern portion of Farmington Bay, Great Salt Lake. We estimated that this consistent water source creates and maintains between 800 and 1400 hectares of important sheetflow wetland habitat. NDSD, Jacobs Engineering, Utah Division of Water Quality (UDWQ), Wasatch Front Water Quality Council (WFWQC), and OreoHelix Ecological are in the preliminary stages of evaluating environmental and ecological dynamics and the food web of these wetlands downstream of NDSD Outfall 001. Based on our first year' ecological research in these wetlands, we have determined that between 4000 to 16,500 shorebirds and waterfowl occupied these wetlands on any given survey date in 2020 and that these wetlands consisted of *top-heavy, mutualistic positive feedback loops* within the food web starting with nutrients from NDSD outfall to primary producers (benthic algae, macrophytes) to secondary consumers (macroinvertebrates) to tertiary consumers (mainly shorebirds and waterfowl) and back to nutrients via consumer excretion. In addition, nutrient levels, including SRP, declined substantially from NDSD outfall as waters flowed into Farmington Bay and no harmful cyanobacteria blooms were detected. Any changes in the amount and timing of wetted area in NDSD sheetflow wetlands based on management operations will affect macroinvertebrate metacommunity dynamics and viability, as well as waterfowl and shorebird population dynamics. Continued research and development of food web-nutrient dynamics models are imperative to help determine when and for how long any changes in NDSD outflow flow levels could affect the ecology and food web in these wetlands.

Table of Contents

List of Figures

List of Tables

Appendices

Introduction

Great Salt Lake (GSL) Utah, U.S.A., a relic of ancient Lake Bonneville, is the fourth largest terminal lake in the world. GSL and its wetlands along with its freshwater tributaries are designated as a Hemispheric Site within the Western Hemisphere Shorebird Reserve Network, signifying the vital importance of habitat complexity and function necessary to support roughly ten million migratory and resident aquatic birds annually as many migrate from breeding grounds as far north as the Arctic Circle and return to wintering areas as far south as Argentina (UDWQ 2014, Sorensen et al. 2020). Shorebirds, waterbirds and waterfowl utilize the wetlands and open water for foraging, staging, breeding, brood-rearing and molting. For Snowy Plover (*Charadrius nivosus*), American Avocet (*Recurvirostra americana*), and White-faced Ibis (*Plegadis chihi*), the GSL ecosystem represents their species' largest breeding colonies or staging grounds in the world (Paul and Manning 2002).

Approximately 75% of all wetlands in Utah (the second driest state in the U.S.) are found along the freshwater tributaries of Great Salt Lake. Of the nearly 182,000 ha that comprise GSL wetlands, approximately 61,000 ha[1] are located in the southeast portion of the lake surrounding Farmington Bay (FB) (Hoven et al. 2011, 2014, Miller et al. 2011, Miller 2014). The importance of GSL and associated wetlands to migratory and resident birds and its significance to the ecology and economy of the region is well documented (Gwynn 2002, Bioeconomics 2012, UDWQ 2014, Gardner et al. 2020).

Figure 1. Thousands of migratory waterfowl and shorebirds rely on wetlands in and around Farmington Bay, Great Salt Lake, UT. Illustrated here is the wetland habitat dependent on North Davis Sewer District outflow waters and several thousand birds.

[1] This wetland habitat estimate appears to be much larger during low water years. Habitat area fluctuates depending upon flow rates and lake level and depends upon definition of habitat - all in flux. We crudely estimate that suitable shorebird habitat in Farmington Bay area during low water years is likely closer to 5300 ha (See
NDSD Wetlands and Potential Farmington Bay Suitable Shorebird Habitat).

Under the federal Clean Water Act and Utah state law, Utah Department of Water Quality (UDWQ) is responsible for 'restoring and maintaining the physical, chemical, and biological integrity' of GSL, and because of its uniqueness and wide diversity of habitats, UDWQ has designated GSL its own 'beneficial use-protection class', divided into five subclasses that include wildlife protection of "a quality sufficient for waterfowl, shorebirds, and other water-oriented wildlife, including their necessary food chain" (UDWQ 2014).

The wetlands of Great Salt Lake are some of the most biologically productive in the world due to their geologic history, chemistry, topography, and terminal location in the drainage. Nutrients from the surrounding landscape provide primary producers (e.g., algae, submerged aquatic vegetation (SAV), and emergent vegetation (EV)) with sufficient energy to stimulate substantial amounts of secondary production (i.e., biomass), mostly in the form of macroinvertebrates, which in turn are made available as essential food energy resources to the millions of birds that have come to depend on this consistent and diverse food supply. We have documented over 75 phytophilus (aquatic plant associated) and benthic invertebrates and about 30 zooplankton taxa in GSL wetlands and Farmington Bay (Richards 2014, Marden and Richards 2017). In any one square meter of substrate in the wetlands and Farmington Bay, about 15 to 25 macroinvertebrate taxa at very high densities; sometimes > 75,000 individuals per square meter can occur (Richards 2014, this document).

Although the security that Farmington Bay wetland habitats provide is essential for migratory and resident bird viability; perhaps more importantly are the abundant food resources (primarily invertebrate secondary production and SAV seeds and drupelets) that these wetlands generate throughout most of the year and particularly during critical times of year, i.e., staging, migration, rearing young, etc. Individual bird condition and survival and therefore population viability depend upon these food resources. As we have discovered in this past year's research, the food web of these wetlands is complex with what appears to be previously undocumented *top-heavy, mutualistic, positive feedback loops* between nutrients, primary producers, and secondary and tertiary consumers.

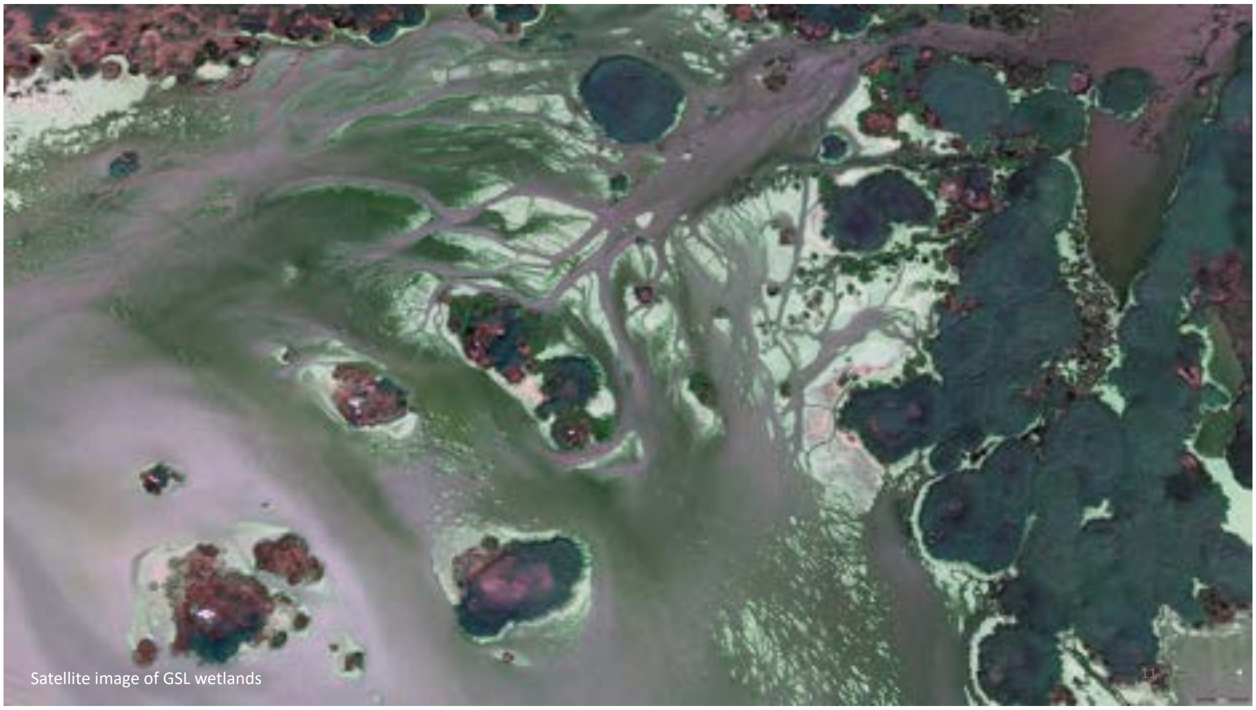


Figure 2. Google Earth satellite image showing the diverse habitat that occurs within North Davis Sewer District wastewater treatment facility dependent wetlands. Dark green patches on right side of image are Phragmites sp. hammocks. Area on left is start of our Unit 3 study section (See Methods). On close inspection you can see bird and coyote tracks, as well as how the water braids through the system as it meanders to Farmington Bay.

Justification

Farmington Bay (FB) has been the receiving water from the Greater Salt Lake City Metropolitan area and its land use practices within the drainage for close to two centuries. Severe reduction and loss of freshwater supply is now the biggest threat to production and survival of Farmington Bay's wetland ecosystems (Great Salt Lake Institute, West Minster College). Most of the Bay's freshwater comes from the Jordan River and or POTW (water treatment facility) outflows.

The North Davis Sewer District's (NDSD) wastewater effluent provides on average 20 to 22 million gallons per day (MGD) of treated wastewater to the northeastern portion of Farmington Bay. We estimated that this consistent water source creates and helps maintain between 800 and 1400 hectares of important sheetflow wetland habitat. NDSD, Jacobs Engineering, Utah Division of Water Quality (UDWQ), Wasatch Front Water Quality Council (WFWQC), and OreoHelix Ecological are in the preliminary stages of evaluating environmental and ecological dynamics of these wetlands based on the objectives outlined in the DWQ approved NDSD 2020 Field Sampling Plan (Jacobs and WFWQC 2020).

An intensive ecological survey was requested to provide a baseline inventory of these wetland resources including water quality, biodiversity, primary production, secondary production, bird use and overall ecological health to optimize the use of NSDS Outfall 001 into the wetlands (NDSD 2020 Field Sampling Plan (Jacobs and WFWQC 2020). The ecological research that we conducted on NDSD sheetflow wetlands in 2020 is presented in this report and supplements our continuing ecological monitoring and evaluation of the main body of Farmington Bay (Marden and Richards 2017, Hoven et al. 2011, Hoven et al. 2014, Miller et al. 2011, Richards 2014, 2015, 2018, 2020a, 2020b). Results from these and future analyses will also be used in comprehensive food web models designed to provide the most relevant and comprehensive scientific guidance to managers of these important wetlands.

NDSD Wetlands and Potential Farmington Bay Suitable Shorebird Habitat

The approximately 61,000 ha of Farmington Bay wetland habitat reported by Hoven et al. (2011, 2014), Miller et al. (2011), Miller (2014) and others does not appear to be a justified amount for wading shorebird habitat during low water years. These estimates also likely do not take into account foraging strategies and feeding depth requirements of wading shorebirds. For example, feeding depths of American Avocet (*Recurvirostra americana*) (Figure 3A), Black-necked Stilt (*Himantopus mexicanus*) (Figure 3B), White-faced Ibis (*Plegadis chihi*) (Figure 3C), Long-billed Curlew (*Numenius americanus*) (Figure 3D), and others are limited by their leg and bill length and prefer shallow water for visual or tactile predation (Sorensen et al. 2020). Although a few species such as Red-necked (Northern) Phalarope (*Phalaropus lobatus*) (Figure 3E), in addition to wading, often visually feed while swimming (Sorensen et al. 2020).

A

B

C

D

E

*Figure 3. Wading shorebirds in NDSD sheetflow wetlands prefer to visually feed while wading at water depths limited to their bill and leg lengths. American Avocet (Recurvirostra americana) (**A**) also feed by touch using a sweeping motion of their beak. Black-necked Stilt (Himantopus mexicanus) (**B**) are mostly visual predators. White-faced Ibis (Plegadis chihi) (**C**) and Long-billed Curlew (Numenius americanus) (**D**) are also mostly visual predators, and all are limited to hunting at water depths by bill and leg length. Red-necked (Northern) Phalarope (Phalaropus lobatus) (**E**) wade and swim for prey.*

We roughly estimated that during low water years such as 2019, suitable wetted habitat for wading shorebirds in Farmington Bay, including NSDS sheetflow wetlands was as little as 5300 ha (Figure 4). These revised estimates, although not very precise and in need of refinement, suggest that North Davis Sewer District dependent sheetflow wetlands may contribute from 15 to 27% of suitable wading shorebird habitat in Farmington Bay during low water years, including that which occurred during our research in 2020.

Figure 4. Suitable shorebird habitat during low water years is area outside of area outlined in red in this Google Earth image. Unsuitable habitat inside red area is water that is likely too deep for wading shorebirds to forage (see Figure 3). The rough estimate of unsuitable habitat in this image is about 3500 ha and suitable habitat is estimated at about 5300 ha, including NDSD 800 to 1000 ha of sheetflow wetlands.

Studies

We conducted several sub-studies on NDSD wetlands in 2020 as outlined in NDSD SOP and approved by DWQ, including:

- Chemistry and nutrient dynamics, water quality
- Bird counts and dynamics
- Bird/macroinvertebrate food web dynamics
- Invertebrate diversity
- Benthic algae and phytoplankton sampling
- Zooplankton assemblages

- Aquatic vegetation percent cover, biomass
- Plant diversity/inventory.

Methods

Method details can be found in NDSD 2020 Field Sampling Plan (Jacobs and WFWQC 2020) and are also highlighted in the following.

Study Area

We delineated the NDSD outfall dependent wetlands into six sub-sampling units shown in Figure 5.

Figure 5. Study area of NDSD dependent wetlands with units shown in yellow in this satellite image and seven bird exclosure cages labeled as orange pins in February/March 2020. The numbering of the units followed the flow of the water from the treatment outfall to Farmington Bay, east to west. The surface area of wetlands covered in water varied throughout the year with most of the study area outlined in red having water in late winter/early spring but much less in late summer/autumn. Wetlands are approximately 2000 to 3000 acres or 800 to 1200 hectares and almost completely dependent on NDSD treatment facility water, which enters the wetlands at an average rate of about 20 million gallons per day.

Sampling dates, types of samples collected, and coordinates for exclosure cages are in Table 1.

Table 1. Sampling dates 2020. ^{C} = chemistry; ^{B} = bird counts; ^{M} = macroinvertebrates. Exclosure cage latitude and longitude.

21-Jan^{C}	1-Apr$^{C, B, M}$	11-May$^{C, B, M}$	15-June$^{C, B, M}$	2-July^{M}	7-Aug$^{C, B}$	2-Sept$^{C, M}$	7-Oct$^{C, B, M}$	2-Nov^{M}
18-Feb^{C}	2-Apr$^{B, M}$	14-May$^{, M}$	18-June$^{C, B}$	10-July$^{B, M}$	16-Aug^{B}	17-Sept$^{C, B, M}$	23-Oct$^{, M}$	3-Nov^{M}
31-March^{B}	7-Apr$^{B, M}$	27-May$^{C, B, M}$	25-June^{B}	13-July$^{C, B, M}$	20-Aug$^{C, M}$	28-Sept^{B}	19-Oct^{B}	6-Nov^{M}
	17-Apr$^{B, M}$	28-May$^{C, M}$		14-July^{M}	25-Aug$^{, M}$		29-Oct$^{B, M}$	9-Nov^{M}
	27-Apr$^{B, M}$			28-July$^{, M}$	30-Aug^{B}			18-Nov$^{B, M}$
	29-Apr$^{B, M}$			29-July$^{B, M}$				

Exclosure Cage	Latitude	Longitude
1a	41.083750°	-112.139710°
3a	41.071750°	-112.158760°
4a	41.083000°	-112.179418°
4b	41.077920°	-112.180872°
4c	41.075350°	-112.179180°
5a	41.079130°	-112.192120°
6	41.072193°	-112.190043°

Chemistry Data

Chemistry and water quality variables were collected during each of the twenty-six sampling dates (Table 1). Data was collected using an Insitu-Aquatroll 600 sonde equipped with RDO, pH, and conductivity sensors. Chemistry was analyzed at the certified North Davis Sewer District laboratory (Table 2).

Table 2. List of chemistry variables analyzed at North Davis Sewer District laboratory and Sonde.

NDSD Lab		
Total Phosphorus (TP)	Total Ammonia (NH_3)	Total Dissolved Solids (TDS)
Total dissolved Phosphorus	Nitrate/Nitrite	pH
Soluble Reactive Phosphorus (SRP)	TKN	Volatile Suspended Solids (VSS)
TKN-TN		
Sonde		
Conductivity (uS/cm)	Salinity (PSU)	Total Dissolved Solids (TDS)(ppt)
DO (mg/L)	DO (%Saturation)	pH
Temp (^{0}C)		

Bird Exclosure Cages

Bird exclosure cages were built using metal fence posts wrapped with 1 -inch mesh plastic fencing material on all sides except the bottom. Fencing material was secured with zip-ties to allow for easy removal for collecting macroinvertebrate samples from inside the cages. Bottom of sides of cages were kept at water level to prevent birds from entering underneath. Cages were 10-ft by 4-ft.

Benthic Invertebrate Sampling

Benthic macroinvertebrates were collected using a 15-cm by 15-cm mini Surber sampler with 1-mm mesh or by using a PVC quadrat of the same dimensions. Replicate samples were collected inside and outside of exclosure cages and composited by inside vs. outside cages. Benthic sediment depth sampled was 5 cm using a garden trowel or shovel method. See our YouTube Video for more details:

https://youtu.be/KBS5DkjZe20

A **B** **C** **D**

*Figure 6.**A**.Often we used WFWQC airboat to access sections of the study area farthest away from Antelope Island Rd. More often than not, we waded to study locations. **B**. This image shows researchers installing bird exclosure cage in Unit 4. **C.** American Avocets feeding near exclosure cage in Unit 4. View is looking north to Antelope Island causeway, early April 2020. Note: birds were hungry enough to lose fear of us and our airboat. Photo was taken 10 minutes after our arrival via airboat in early April 2020. **D**. Researchers discussing implementation of macroinvertebrate diversity traps in Unit 3.*

Plant Sampling and Surveys

Primary producer (plants i.e., benthic algae, submerged aquatic vegetation, emergent vegetation bulrush, not phragmites/cattails) sampling was conducted on three separate days in autumn. Plant height data were collected on October 1, 2020 from Units 3, 4, and 5 by randomly tossing a 15-cm by 15-cm PVC quadrat twenty times within each unit. Percent cover and dry weight biomass data were collected on October 5th and 6th, 2020. Percent cover was estimated from Units 3, 4, 5, and 6 by randomly tossing a 1-m^2 PVC quadrat twenty times, visually estimated and photos were taken of each quadrat for archival (see Appendix 15 for photographs of plant cover). Dry weight biomass was estimated by taking twenty random 15-cm by 15-cm samples from Units 3, 4, 5, and 6, transported to South Davis Sewer District laboratory and oven dried at 100 ^{0}C for 4 hours, then weighed.

Macroinvertebrate Inventory

We deployed fifteen to twenty custom made horizontal activity traps at several locations in Unit 3, the most diverse habitat unit (Figure 2) in summer months. Traps (Figure 7) were deployed for two nights at the sediment water interface with their openings facing upstream, retrieved, and contents cursorily evaluated by Wasatch Front Water Quality Council staff and then shipped to River Continuum Concepts lab in Manhattan, MT for professional taxonomic identification.

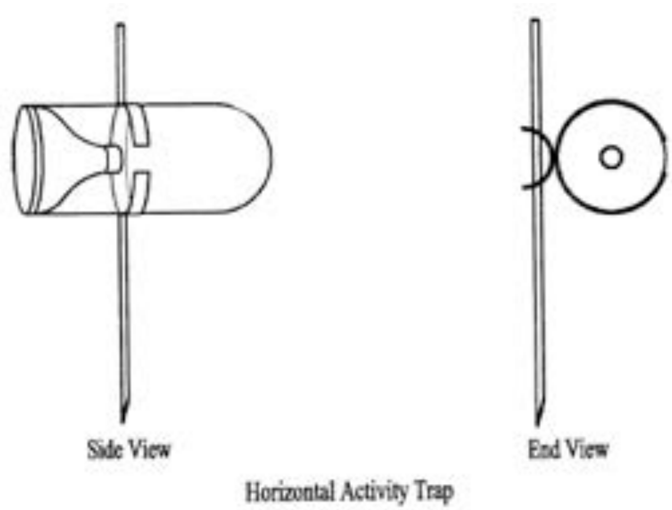


Figure 7. Custom made horizontal activity traps used to conduct aquatic invertebrate inventory from Unit 3. Illustration from Figure 1, Becerra-Jurado et al. 2008.

Laboratory Macroinvertebrate Taxonomy Methods

See our YouTube video for an overview of taxonomic methods:

www.youtube.com/watch?v=n0q5yGVi2Tg

Midges (Family Chironomidae) are often called chironomids. Larval taxonomy below family level is typically only taken down to subfamily or tribe. However, experts can identify midge larvae to genus and on occasion, species (Figure 8).

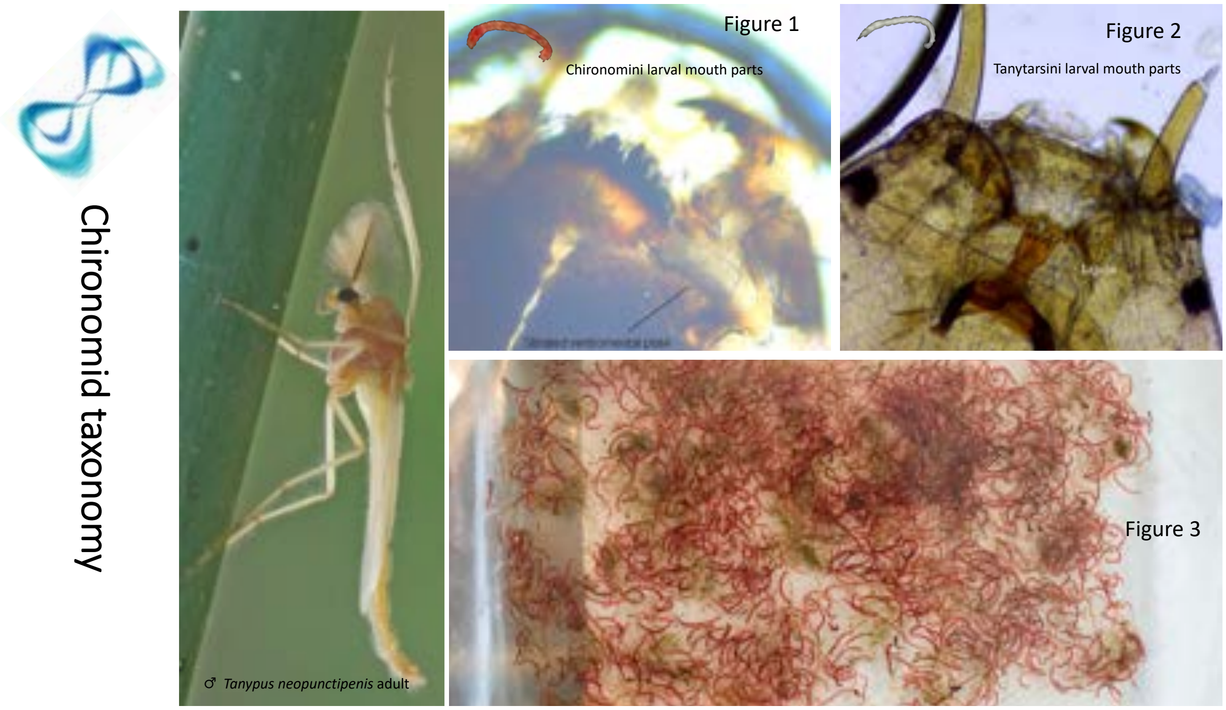


Figure 8. Larval mouthparts are required for taxonomic i.d. In Figure 1, the striated ventromental plate distinguishes the tribe Chironomini, of which the genus Chironomus are a member. The mouth part known as the ligula shown in Figure 2 distinguishes the tribe Tanytarsini of which Tanypus neopunctipenis is a member. The red midge larvae shown in Figure 3 are Chironomus collected from a 0.1 square meter sample from the wetlands in May 2020.

Zooplankton

Zooplankton samples were collected using a 64 μm mesh plankton net (

Figure 9). The net was placed on top of the substrate facing into the direction of flow and allowed to collect zooplankton for 1-minute. Water depth and flow rate was measured or estimated. Area of the net covered with water was also estimated based on water depth and area of wetted net. These values gave us an estimate of volume sampled.

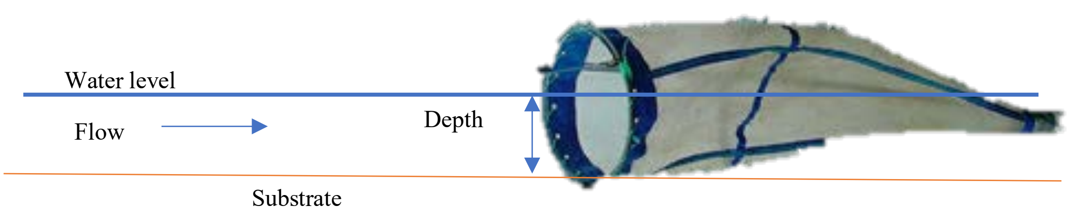


Figure 9. Diagram of zooplankton sampling method.

Zooplankton samples were then placed into 70% isopropyl final dilution and taxonomically evaluated by River Continuum Concepts, Manhattan, MT.

Bird Counts

“Counting birds is just like counting trees; except birds can hide and can fly away very, very, fast”

A

B

Figure 10. Bird count accuracy and identification was based on proximity to observer and number of birds in an area. In A, accuracy and identification was straightforward, there were three White-faced Ibis (Plegadis chihi). In B, accuracy and identification were more difficult and counts less precise as bird numbers increased.

Bird counts were conducted every two weeks beginning on April 1, 2020 and are ongoing. Counts were made from two locations on Antelope Island Road, one at Unit 4 (Lat: 41.089224°; Long: -112.169089°) and one at Unit 5 (Figure 5, Lat: 41.084731°; Long: -112.201049°) so as to have complete coverage of the wetlands that were visible from the road. An effort was made to conduct counts shortly after sunrise, however on several occasions, counts were made between mid and late morning. Birds were observed using a Vortex Fury HD 5000 10 x42 magnification binoculars with built in range finder and photographed using a Nikon z7 camera with 500 mm lens. Several dozen high resolution images (45.7 mp) were taken during observations to better estimate bird counts and to archive and record abundances. Images will be made available on a server in 2021. Observations lasted for a duration of thirty minutes at each location. Starting at the end of May 2020, additional observations and counts were made in close proximity to exclosure cage 6A (Figure 5) after walking along the sandbar that separates the wetlands from Farmington Bay.

Birds were identified to various taxonomic levels depending on distance from observer and whether birds were in taxonomically distinguishable breeding plumage. The most common bird identifications of birds that were close enough to positively identify were: American Avocet (*Recurvirostra americana*), Black-necked stilt (*Himantopus mexicanus*), White-faced Ibis (*Plegadis chihi*), Marbled godwit (*Limosa fedoa*), Long-billed curlew (*Numenius americanus*), phalarope (*Phalaropus lobatus, Phalaropus tricolor*), Franklin's gull (*Leucophaeus pipixcan*), California gull (*Larus californicus*), Northern shoveler (*Spatula clypeata*) , Canada goose (*Brant canadensis*), Snow Goose (*Anser caerulescens*), Norther harrier (*Circus hudsonius*), Great blue heron (*Ardea herodias*), Common raven (*Corvus corax*), and American coot (*Fulica americana*). All others were grouped into shorebirds or waterfowl. Songbirds were not identified. In general, most analyses presented in this report were grouped as shorebirds or waterfowl.

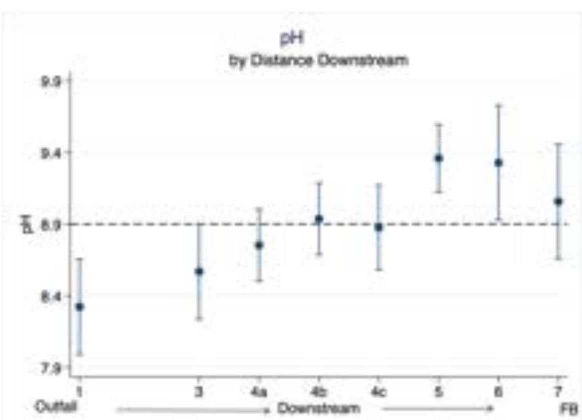
Statistical Analyses

Several standard statistical methods were conducted including summary descriptive statistics. Several regression models, dependent on response variable distributions, were developed including linear, quadratic, negative binomial (count data), and fractional (percent data) regressions. Regression models were evaluated using log likelihood, AIC, and BIC and the best fit model was used as the final model. Regressions were also made on residuals when appropriate. Predictive marginal responses were made on several data sets after appropriate regressions. All analyses were made using Stata/IC 16.1 for Mac (64-bit Intel). Graphs were made either using Stata or Excel.

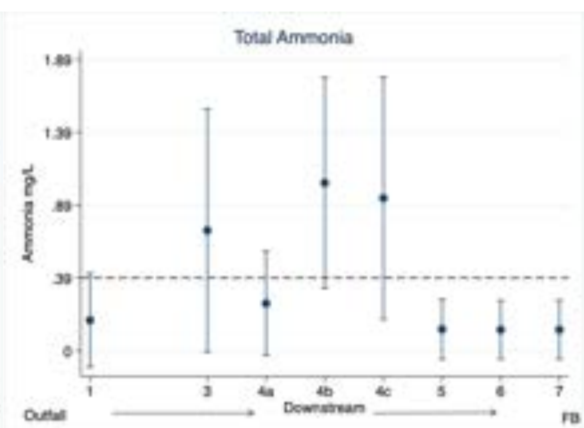
Results

Water Chemistry

Water chemistry data continue to be analyzed. The following graphs of predicted concentrations of chemistry variables derived from linear and negative binomial regressions (Figure 11, Figure 12, Figure 13). pH increased significantly downstream from the treatment facility, shown in Figure A, Ammonia was significantly higher in the central units, typically where there was more bird activity as shown in Figure B. These elevated ammonium concentrations are perhaps due to droppings from extremely high bird populations recorded in this area followed by subsequent assimilation at downstream locations. The elevated pH, an indication of elevated primary production supports this hypothesis, although conversion to nitrate (nitrification) also appears to be occurring. Volatile suspended solids and total dissolved solids were significantly higher at the junction of wetland water with Farmington Bay water and in Unit 4a shown in Figures C and D. We need to determine why unit 4a had higher concentrations of these two variables.



A



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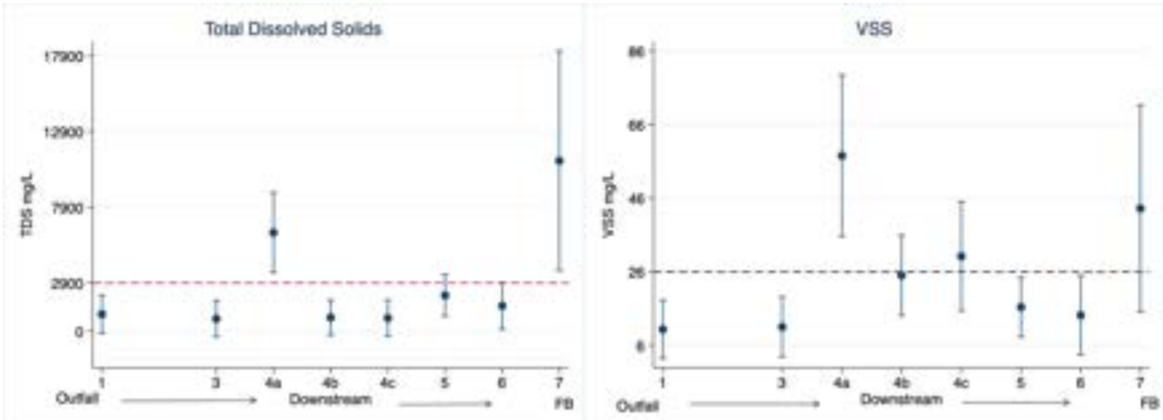
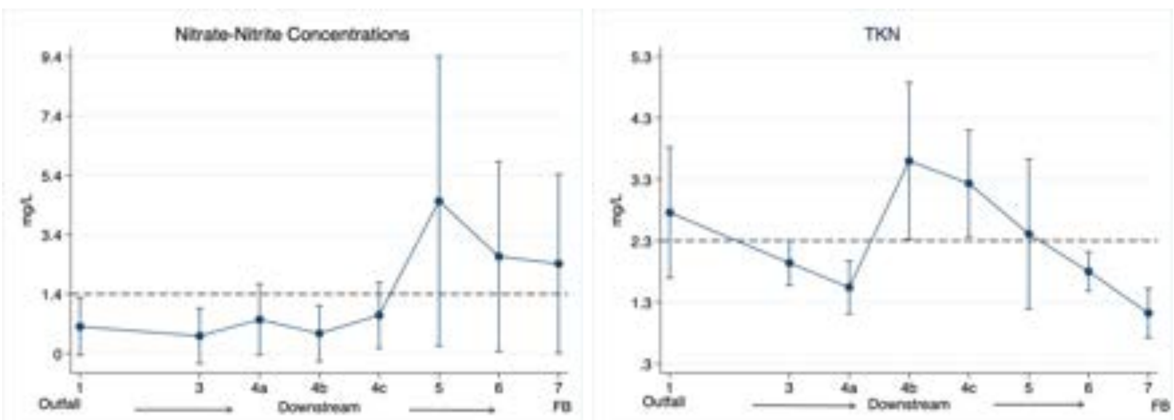


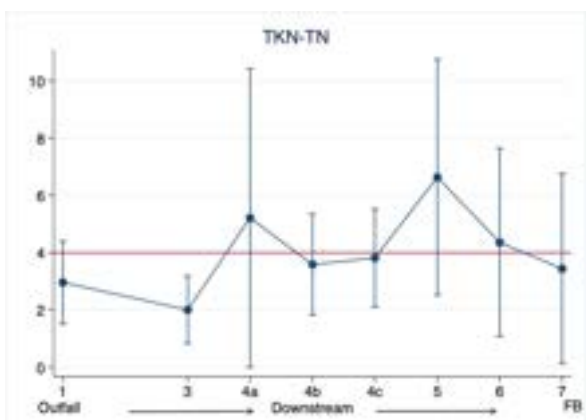
C D

Figure 11.Predicted mean and 95% Cis for four chemical variables from upstream to downstream of NSDS outfall.

Nitrate-nitrite concentrations were highest downstream. TKN was highest in mid reaches of the wetlands and TKN - TN was mostly similar throughout.



A B



C

Figure 12. Predicted mean and 95% CIs for three nitrogen variables from upstream to downstream of NSDS outfall.

Most notably, orthophosphate concentrations significantly decreased as treatment facility waters moved through the wetlands towards Farmington Bay (Figure 13). Mean ortho-P concentration was about 4.5 mg L^{-1} near the outfall. By the time water reached Farmington Bay, labeled here as site 7, mean concentrations were at 0.04 mg L^{-1} a decrease in over two orders of magnitude (Figure 13). Mean orthophosphate concentrations were below Utah Division of Water Quality's goal of 1 mg L^{-1} total phosphorus by time the water reached sites 5 and 6 (Figure 13). This reduction could have important implications for managing Farmington Bay.

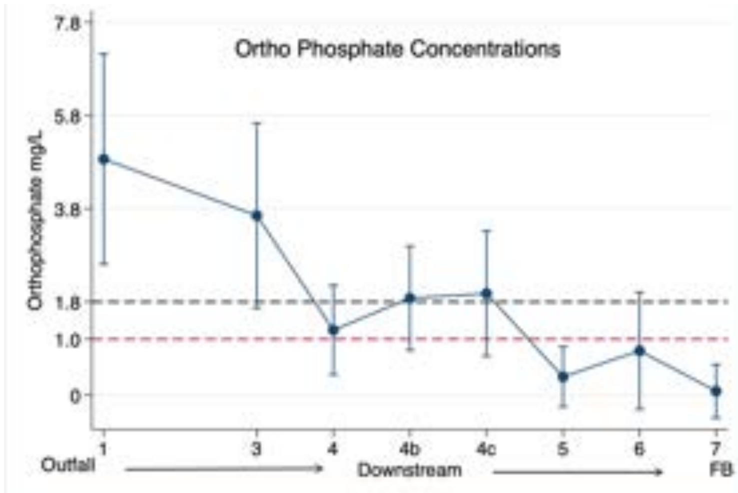


Figure 13. Predicted marginal concentrations of orthophosphate (mg L-1) in the wetlands from NDSD outfall downstream to Farmington Bay. Mean and 95%CIs. Black dotted line is grand mean; red dotted line is DWQ recommended effluent concentration.

Primary Producers

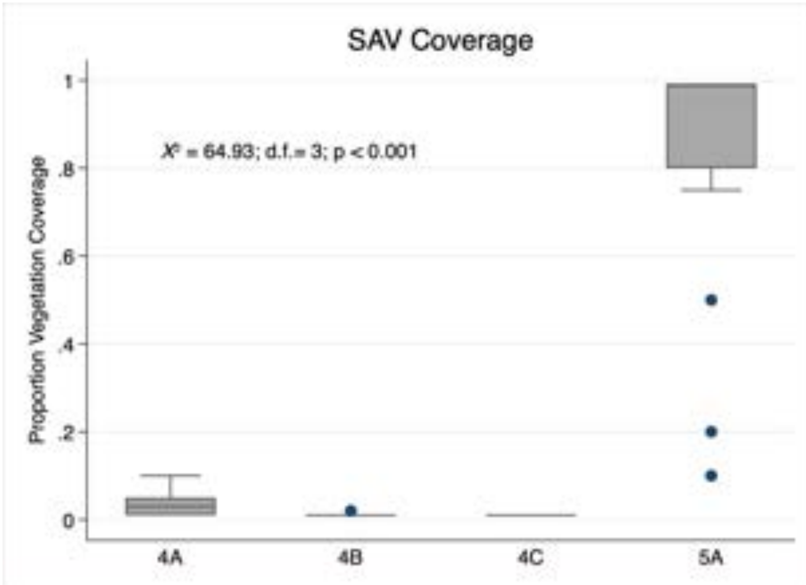
Benthic Algae and Phytoplankton Assemblages

We did not see or measure any cyanobacteria blooms at any time in the wetlands. Reasons for this may involve one or more of several factors, including, but not limited to: short residence time, low salinities (below the range for *Nodularia* sp.), or nutrient ratios that favor other green algae (Marden and Richards 2017, Richards et al. 2019). Benthic algae and phytoplankton samples are currently being processed by Rushforth Phycology

Percent cover of aquatic primary producers varied temporally and between units. In spring and throughout much of the summer, much of Units 4, 5, and 6 were bare of macrophytes and green filamentous algae. By end of summer much of these areas were covered by SAV including *Stuckenia pectinata* (Fennel-leaf pondweed), *Zannichellia palustris* (Horned pondweed), *Schoenoplectus americanus* (Threesquare bulrush), *Bolboschoenus maritimus* (Alkali bulrush), *Lemna gibba* (Humped duckweed), *Lemna minor* (Lesser duckweed) and the filamentous green algae, *Cladophora* sp.(Figure 15, Figure 17, Figure 18, Figure 19, Figure 20, Appendix 12).

Median standing crop dry weight biomass of primary producers throughout the units was 152 g m^{-2} and up to 298 g m^{-2} (75th percentile) towards the end of the growing season on October 6th (Figure 15).

Benthic algae have extremely high turnover or primary production rate, which likely can be measured in hours, particularly given the high grazing of the algae by midge larvae, which will be discussed later in this report. SAV on the other hand, have much lower primary production rates. Unit 3 had 50% plant cover, Unit 4 had 1%, Unit 5 had 95%, and Unit 6 had 90% cover on September 2nd. Data analysis is ongoing including primary production rate values for food web-nutrient dynamics models (see Ongoing and Future Research).



Unit	Median	25th percentile	75th percentile
4A	0.03	0.01	0.05
4B	0.01	0.01	0.01
4C	0.01	0.01	0.01
5A	0.99	0.8	0.99

Figure 14. Proportion vegetative coverage of four locations within NDSD wetland on September 2, 2020. Twenty 1-m² quadrats at each location (see Appendix 15).

Table 3. Descriptive statistics of primary producer standing crop dry weight biomass (g m⁻²) by type of producer and unit on October 6, 2020.

Unit 3	Mean	s. d.	50th	25th	75th
Benthic algae	270.03	205.29	260.46	94.51	445.62
Cladophora sp.	36.98	71.42	12.36	3.66	25.42
Potamogetonaceae	20.39	19.28	16.73	5.53	35.24
Total	*126.88*	*178.56*	*25.42*	*8.52*	*213.42*
Unit 4					
Benthic algae	222.12	59.61	222.12	179.97	264.27
Lemnaceae	0.34	.	0.34	0.34	0.34
Potamogetonaceae	0.95	.	0.95	0.95	0.95
Total	*111.38*	*132.42*	*90.46*	*0.65*	*222.12*
Unit 5					
Benthic algae	26.71	18.34	25.19	12.40	44.78
Potamogetonaceae	312.93	168.35	255.08	199.91	351.72

Total	*173.91*	*188.14*	*114.23*	*25.19*	*260.14*
Unit 6					
Benthic algae	37.82	47.41	27.90	9.60	37.03
Potamogetonaceae	331.12	143.24	315.59	237.58	385.86
Total	*236.84*	*183.85*	*240.68*	*44.11*	*358.24*
Grand Total	***180.48***	***184.94***	***152.37***	***19.63***	***297.51***

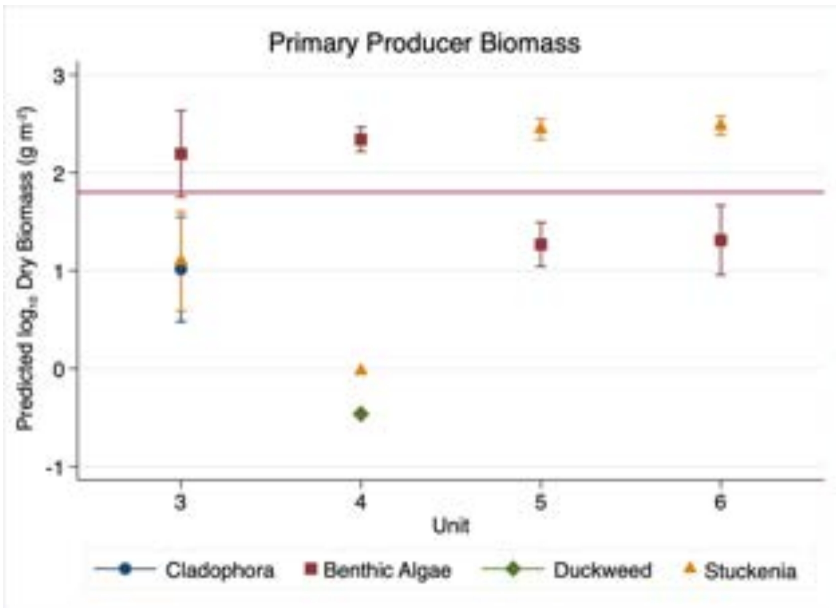


Figure 15. Predicted standing crop dry weight biomass g m^{-2} of SAV and benthic algae on October 6, 2020 by sampling unit.

Plant height (cm) varied between units. Figure 16 shows changes in four types of plant heights among three units on October 1, 2020.

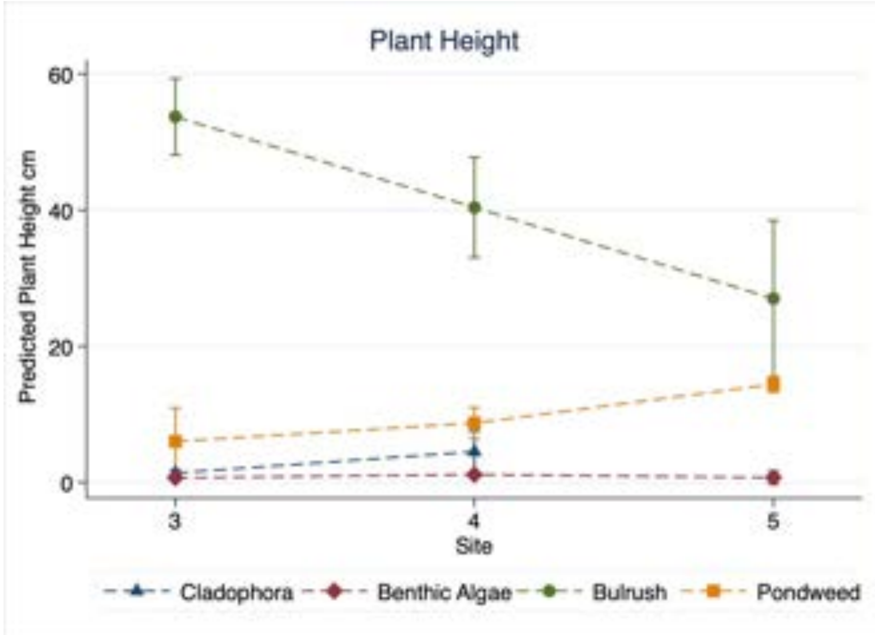


Figure 16. Plant height (cm) at the units on October 1, 2020. Data from fifty mini-Surber quadrat tosses at each unit.

Figure 17. Even in late February and early March, vegetation was growing in the slower water. Much of this was the green algae, Cladophora sp. that attached to the previous year's senescent vegetation.

Figure 18. From late summer throughout autumn aquatic vegetation prospered. The short emergent vegetation is Alkali bulrush, Bolboschoenus maritimus. Duckweed, Lemna gibba (Humped duckweed), Lemna minor (Lesser duckweed) and pondweed, Stuckenia pectinata (Fennel-leaf pondweed), Zannichellia palustris (Horned pondweed), were also abundant as was some green algae. Bullrush seeds, pondweed drupelets, and duckweed are important food resources for waterfowl especially when invertebrate abundances are low due to constant consumption by birds throughout the summer. Patches of aquatic vegetation provide shelter for macroinvertebrates from bird predation and allows them to reestablish their populations

In most of Units 4, 5, and 6 aquatic macrophytes began appearing in late summer and dominated the benthos by September. By November, much of the SAV had senesced and was dislodged from the substrate via wind and wave action and floated into Farmington Bay. These successional changes resulted in a major shift in habitat and ecosystem function from mostly bare substrate dominated by benthic algae, which consequently affected macroinvertebrate assemblages and bird foraging strategies (see Waterfowl and Shorebird Feeding Ecology).

Figure 19. Typical habitat in most areas of Units 4, 5. Submerged Stuckenia and emergent Alkali bullrush. In this area there was low levels of Cladophora type green algae

Figure 20. Mid-summer aquatic vegetation began to prosper throughout the wetland but particularly in Units 5 and 6. This is a photo of Unit 6 with several dozen shorebirds, mostly American Avocets and Black-necked Stilts.

Figure 21. As water flowed from the wetlands and entered Farmington Bay on the western edges of Units 5 and 6, it formed a multitude of channels and had lost much of its nutrient load. Slower water allowed benthic algae to accumulate, which provided habitat and food resources for midge larvae and other invertebrates although little security from predators. This habitat was characterized by very shallow water, < 1 cm deep and prime hunting ground for wading shorebirds. Sand bars were with covered by shallow water or exposed, dependent on season and wind action.

Zooplankton

We did not anticipate finding a robust zooplankton assemblage in the NDSD sheetflow wetlands, other than benthic harpacticoids, because of the constant flows. However, we found 24 distinct zooplankton taxa (N = 21 samples) (Table 4). We are continuing sampling and analysis of the zooplankton assemblage including spatial and temporal trends.

Table 4. Zooplankton taxa collected in 21 zooplankton net samples and their relative abundances.

Common Name	Order	Family	Taxon	Relative Abundance
Copepods	Cyclopoida	Cyclopidae	*Eucyclops agilis*	0.2080
			Microcyclops rubellus	0.0509
			Acanthocyclops americanus	0.0063
	Calanoida	Diaptomidae	Diaptomidae	0.0192
			Leptodiaptomus sicilis ♂	0.0017
			Leptodiaptomus sicilis ♀	0.0065
	Harpacticoida	Harpacticoida	Harpacticoida	0.0013
		Canthocamptidae	Canthocamptidae sp.1	0.0002
			Cletocamptus albuquerquensis	0.1001
Cladocerians	Cladocera	Daphniidae	*Ceriodaphnia* sp.	0.0008

			Ceriodaphnia dubia	0.0031
			Daphnia galeata mendotae	0.0002
			Daphnia retrocurva	0.0003
			Simocephalus sp.	0.0050
			Simocephalus mixtus	0.0077
		Chydoridae	*Pleuroxus aduncus*	0.0077
			Leydigia louisi	0.0002
			Leydigia acanthocercoides	0.0055
			Leberis cf. *davidi*	0.0173
			Coronatella cf. circumfimbriata	0.0110
		Moinidae	*Moina macrocopa americana*	0.0206
		Sididae	*Latonopsis occidentalis/australis*	0.0005
		Bosminiidae	*Bosmina longirostris* complex	0.0080
		Ilyocryptidae	*Ilyocryptus* sp.	0.0006
Brine shrimp	Anostraca	Artemiidae	*Artemia franciscana*	0.0013
Rotifers	Plioma	Brachionidae	*Brachionus calyciflorus*	0.0101
		Asplanchnidae	*Asplanchna* sp.	0.5000

Rotifers were the most abundant zooplankton group followed by the copepods (Figure 22).

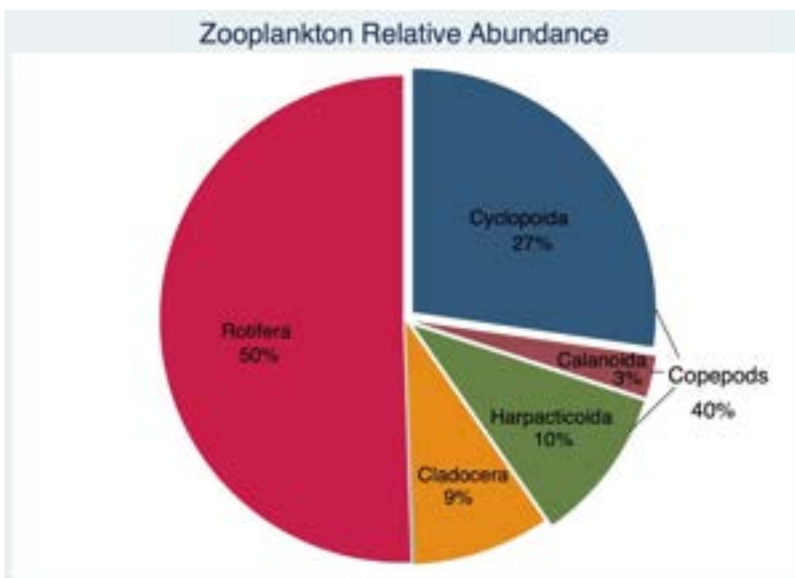


Figure 22. Relative abundance (percent) of zooplankton taxonomic groups found in the wetlands in 2020.

Additional data collection and analysis of the zooplankton assemblage in NDSD sheetflow wetlands is much needed and forthcoming.

Benthic Invertebrates and Bird Predation

Benthic Invertebrate Assemblage

The benthic macroinvertebrate assemblage was moderately diverse but dominated by a few taxa. The benthic assemblage in the wetlands can be loosely divided into benthic and phytophilus taxa. Benthic taxa occur in substrate mostly comprised of loose sediments that dominated in spring and early summer, whereas phytophilus taxa prefer vegetation habitat, which increased in abundance as the season progressed into autumn.

Our sampling methods were biased towards slower moving taxa and consequently some taxa were underrepresented, including corixids and scuds. Table 5 is an example of the typical macroinvertebrate taxa that occurred in the wetlands in spring, 2020.

Table 5. Example of macroinvertebrate taxa collected in NDSD sheetflow wetlands and their relative abundances. From nine benthic samples collected in May 2020. More intensive taxonomic results are pending (see also Macroinvertebrate Inventory)

Order	Family	Subfamily	Genus/species	Relative Abundance
Nematoda/Nemata				0.02%
Amphipoda	Hyalellidae		*Hyalella* sp.	0.39%
Ostracoda				1.25%
Hemiptera	Corixidae	Corixinae		0.01%
Coleoptera	Dytiscidae			0.01%
		Tanypodinae	*Tanypus neopunctipennis (L)*	79.39%
		Orthocladiinae	*Acritotopus* sp.	0.01%
			Cricotopus sp. (P)	0.11%
			Cricotopus sylvestris gr. (L)	1.23%
			Chironomus cf. decorus gr.	11.78%
			Glyptotendipes cf. barbipes	0.05%
		Tanytarsini	*Cladotanytarsus*	0.04%
	Chironomidae		*Micropsectra*	0.05%
	Ephidridae		*Ephydra* cf. *hians*	0.05%
	Dolichopodidae			0.83%
Diptera	Ceratopogonidae		*Palpomyia/Bezzia* complex	0.01%

Other taxa commonly found in the wetlands include odonates ((Zygoptera (damselfies) and Anisoptera (dragonflies)) and two snail (gastropod) taxa, Lymnaeidae and Physidae.

Gastropods, snails

Gastropods (snails) were an important component of the benthic assemblage and a preferred food item of waterfowl and shorebirds in NDSD wetlands. Two families of snails occurred regularly in NDSD sheetflow wetlands, Lymnaeidae and Physidae. Both families are highly fecund and reproduced throughout 2020. Snails are algal grazers and detritivores and play a critical role in the wetland food web. However, snails are easily captured by birds and their populations are likely kept well below carrying capacity. We did not collect near as many snails as their abundant egg masses would have suggested should have been present. Data analysis on their role in the ecosystem of these important taxa is pending and will be emphasized in the 2021 sampling season.

Corixids, water boatmen

Several corixid (water boatman) (Family Hemiptera) taxa occur in Farmington Bay wetlands including, *Corisella* sp., *Hesperocorixa* sp., *Sigara* sp., and *Trichocorixa* sp. (Richards 2014). All of which are selected food items of waterfowl and shorebirds. Aquatic corixid larvae are highly mobile compared with more sessile taxa such as oligochaete worms and midge larvae and are thus more visible but harder to capture by predators. Flying adult corixids are strong flyers and are challenging for birds to capture which allows for relatively quick recolonization if corixid populations are depleted from predations in the wetlands. Corixids are more vulnerable as aquatic larvae in the shallow NDSD wetlands than in deeper often more turbid waters of Farmington Bay, hence far fewer corixids were observed in the wetlands.

Corixid abundances (densities) were observed to be very low in the NDSD wetlands compared to Farmington Bay. We rarely found high densities of corixids, particularly larger instar individuals, in the wetlands, even though in areas where the wetland waters enter Farmington Bay, corixid densities often were in the tens of thousands m^{-2} (Richards and Miller personal observation). Reasons for such low densities of corixids in NDSD wetlands were likely due to intense bird predation. Later in the season, aquatic macrophytes prospered and provided refugia for the corixid population from predation in the NDSD wetlands (see Primary Producers).

Hyalella sp., Scuds

The scud, *Hyalella* sp. was common in the wetlands in 2020. It is also a preferred food item of both waterfowl and shorebirds. *Hyalella* sp. is a detritivore and important taxon within the detritus component of the food web (Figure 34).

Oligochaetes, The Case of the Missing Worm

“Unlike birds and midges, worms can’t fly”
D.C. Richards (personal observation)

Oligochaetes, segmented worms, are one of the most important benthic organisms in freshwaters throughout the world, particularly in productive eutrophic systems. They rival and often surpass chironomid larvae density and biomass and their ability to decompose sediment organic matter, recycle nutrients, and aerate the benthic sediments (Baranov et al. 2016, Mermillod-Blondin 2011, Chaffin and Kane 2010, Holker et al. 2015). Oligochaetes along with midge larvae are a preferred food item of wading shorebirds because of their vulnerability to capture, digestibility, and nutritional content, including high protein (64-73%, Paoletti et al. 2003) and fat contents.

We have documented oligochaete densities >50,000 m^{-2} in nearby Farmington Bay several miles south of NDSD wetlands in 2020. In contrast, oligochaetes were almost non-existent in NDSD wetlands. The most likely explanation for their near absence was wading shorebird predation. Oligochaetes in Farmington Bay avoided predation from wading shorebirds because they occurred in waters too deep ($\geq$ 1 m) for wading birds to forage. Oligochaetes in NDSD wetlands weren’t afforded that option. Water depths in the wetlands throughout much of the year were ideal for wading shorebirds, apparently at the detriment to oligochaetes. Potential other factors for near absence of oligochaetes are being examined over the next several years.

Unlike adult midges, worms can't fly and subsequently have limited dispersal and recolonization abilities. Midge populations in NDSD wetlands are asynchronous and midges are continually transitioning from larvae to pupae to flying adults and returning to the water to deposit their eggs throughout much of the year. Adult midges from other nearby locations can also supplement and help sustain the midge population. On the other hand, once bird predation depletes the NDSD wetland oligochaete worm population, it can take years to rebound. Although, oligochaetes are ubiquitous throughout the drainage, they are relatively poor dispersers. Worm populations within the wetlands cannot reach densities that occur in other productive freshwater ecosystems, with constant predation pressure from birds.

In addition, the low abundance or absence of oligochaete worms from these wetlands likely has a substantial effect on the food web and ecosystem functioning dynamics, starting within the benthic sediments. We do not know of any research that has measured the consequences of low densities or absences of oligochaetes in eutrophic freshwater ecosystems where worms typically are a dominant taxon. Additional research is needed.

Chironomids, midges

Chironomid (Family Chironomidae, common name Midges) larvae were by far the most dominant benthic macroinvertebrate taxa in our NDSD wetland samples as measured by density and biomass. Two species, *Chironomus* cf. *decorus* gr. and *Tanypus neopunctipenis* often were more than 90% relative abundances of all benthic macroinvertebrate taxa (Table 5). More than a dozen other macroinvertebrate taxa and a half dozen other midge taxa occurred in the wetland samples (Table 5), but their densities and biomasses were relatively so low compared to *C. decorus* and *T. neopunctipenis* that they were likely minor food items for birds. In this section, we discuss our preliminary findings on these two taxa.

Chironomus cf. *decorus* gr. larvae are substantially larger than *T. neopunctipenis. Chironomus* cf. *decorus* gr. mean body length was 11.22 mm, whereas *T. neopunctipenis* mean body length was 6.75 mm in samples that we measured larval body lengths (Figure 25). However, *T. neopunctipenis* was substantially more abundant than *C. decorus* in our samples (Figure 23, Figure 24).

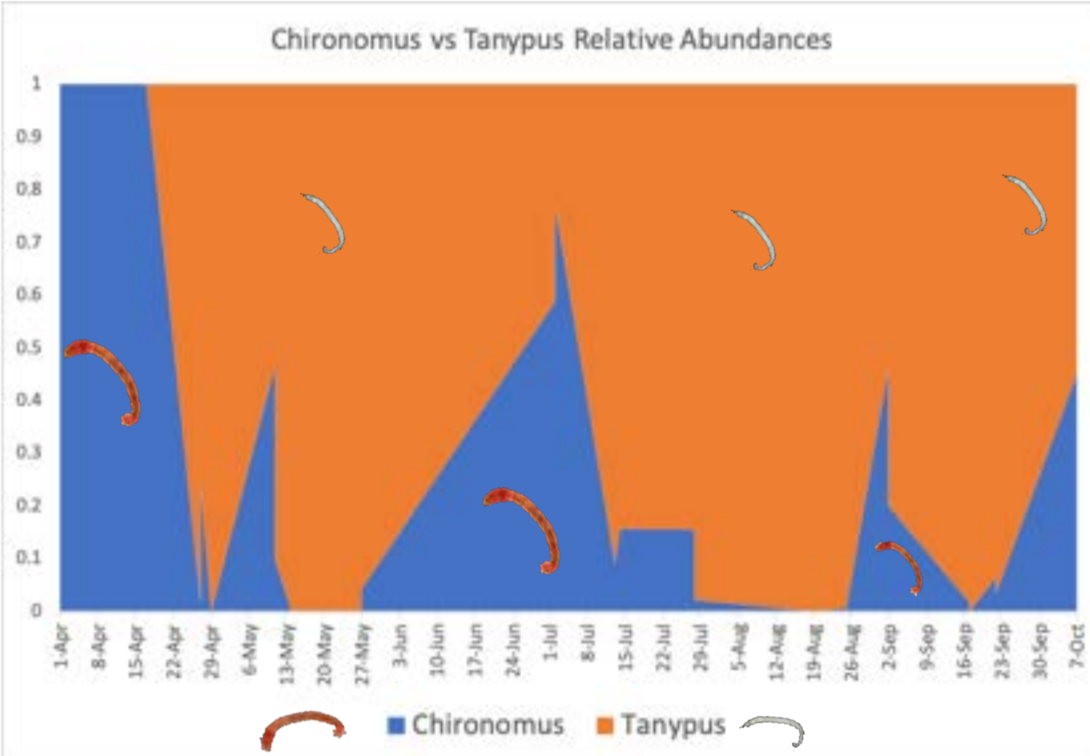


Figure 23. Relative abundances of Chironomus cf. decorus gr. and Tanypus neopunctipenis. It appears that Chironomus decorus may have been tri-voltine, while T. neopunctipenis had asynchronous, continuous overlapping generations within this time period.

Relative abundance of *Tanypus neopunctipenis* was substantially greater than *Chironomus* cf. *decorus* gr. relative abundance both inside and outside of exclosure cages (Figure 24). *C. decorus* relative abundance was slightly greater inside than outside the cages, while *T. neopunctipenis* relative abundance was slightly greater outside the cages than inside, but not statistically significant (Figure 24). We suggest that wading shorebirds prefer the larger *C. decorus* larvae over *T. neopunctipenis* larvae and some feeding selection effects on these midge populations may occur, based on these early results and our experience (Figure 24).

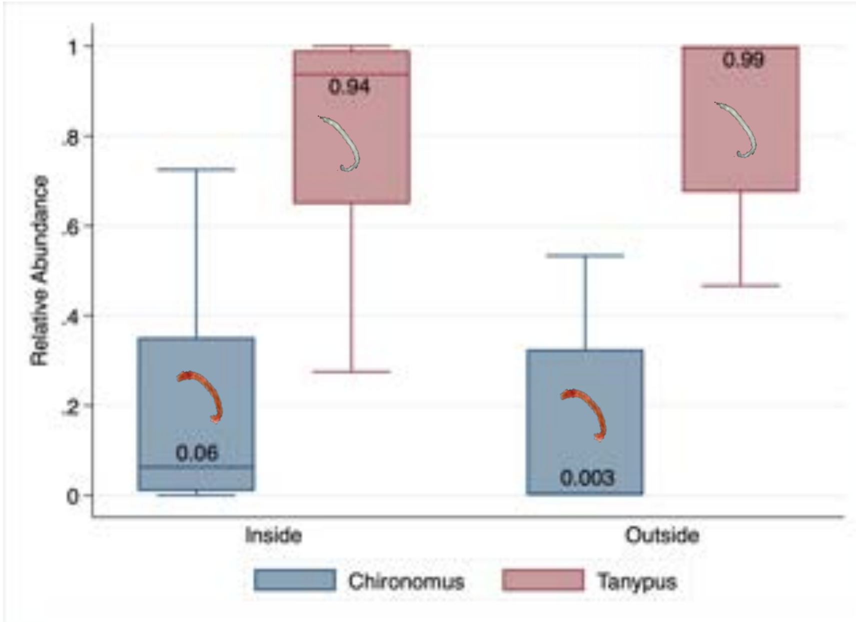
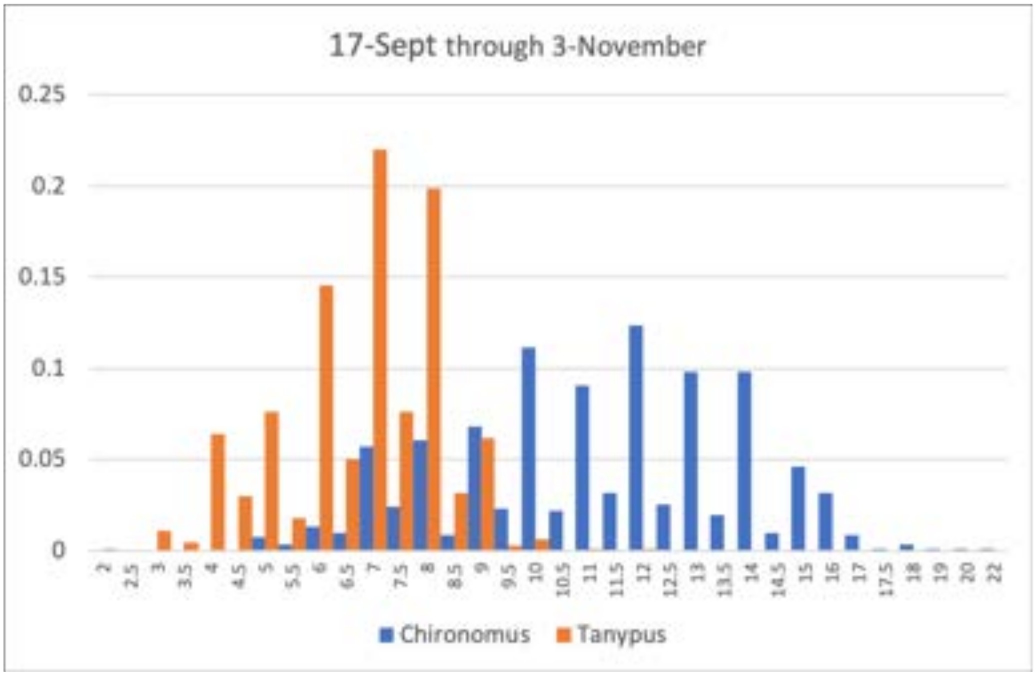


Figure 24. Chironomus cf. decorus gr. and Tanypus neopunctipenis relative abundances inside and outside of bird exclosure cages (median, 25th, 75th, range). Median values are in the boxes. Only data that had matching inside and outside cages from the same dates were used in these boxplots (N = 32). Kruskal-Wallis equality rank test for both species inside vs outside cages: χ^2 = 2.79, p = 0.09.

We have initiated analyses of *Chironomus* cf. *decorus* gr. and *Tanypus neopunctipenis* life history and size class distributions throughout the year 2020 and will continue into 2021. Understanding size class distributions of arguably the two of the most important food items in wading shorebird diets is critical for the management of water levels and timing from NDSD outfall. Size class distributions and descriptive statistics of *C. decorus* and *T. neopunctipenis* from 17-September to 3-November are presented in Figure 25. Additional preliminary life history results of these two taxa can be found in Appendix 11.

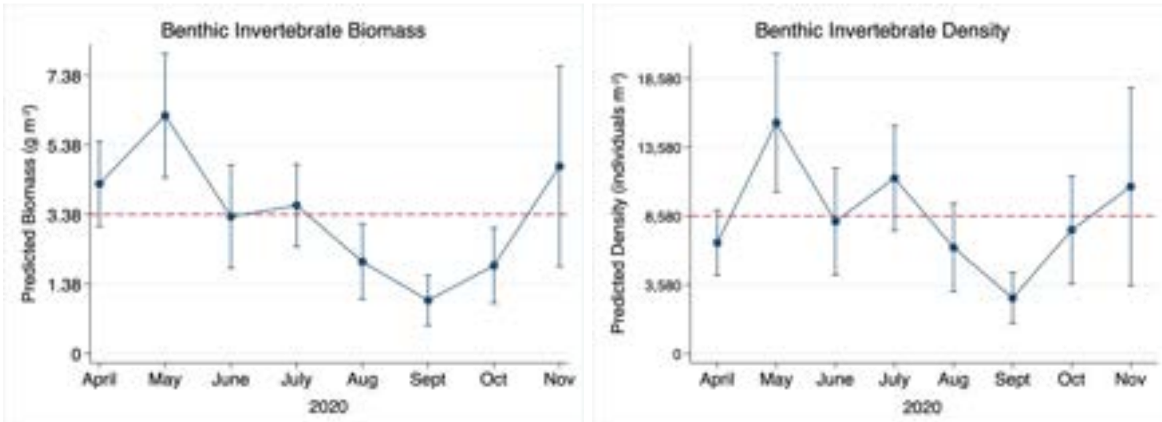


	Mean (mm)	s.d.	Median	25th	75th	max
C. decorus	11.22	2.68	11.5	9	13	22
T. neopunctipenis	6.75	1.45	7	6	8	12

Figure 25. Size class (mm) frequencies and descriptive statistics of C. decorus and T. neopunctipenis from 17 September to 3 November 2020.

Benthic Invertebrates and Bird Predation

Based on our research, benthic invertebrates (e.g. chironomid larvae, corixids, snails, scuds, oligochaetes) were the primary food resource for wading shorebirds in the wetlands in 2020. We identified, counted and weighed benthic macroinvertebrates at approximate 2-week intervals. While this measurement frequency can sometimes be used to measured productivity, it was clear that intensive predatory pressure by shorebirds and waterfowl kept mean numbers and biomass low and nearly continually diminishing throughout the summer and particularly during the fall months. This was notable in that most of the abundant midge species are asynchronous, multivoltine (undergo more than two generations within a single growing season). With the abundant algal biomass and diversity, we would expect that midge populations should have remained abundant and elevated throughout summer and autumn. However, this was not the case. Benthic invertebrate biomass decreased throughout the summer and then started to increase in autumn (Figure 26) and was influenced by bird predation (Figure 27).



A B

Figure 26. Predicted benthic invertebrate biomass (g m-2) and density (indiviudals m-2) from April to November 2020 based on negative binomial regressions and marginal predictive analyses. Mean and 95% Cis shown. Red dotted line is the mean value.

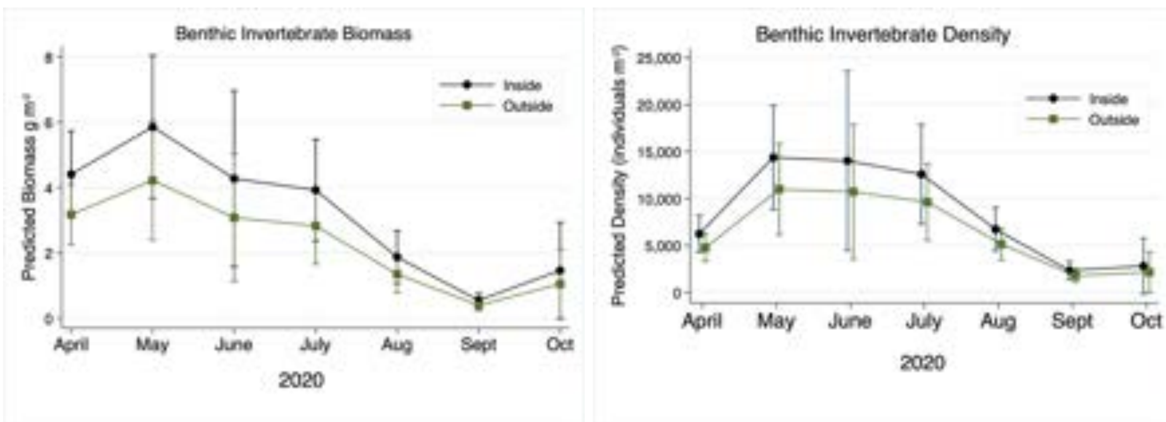


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Figure 27. Predicted benthic invertebrate biomass (g m^{-2}) and density (indiviudals m^{-2}) inside and outside of bird exclosure cages from April to October 2020 based on negative binomial regressions and marginal predictive analyses. Mean and 95% CIs shown.

Further evidence of this predatory pressure on the macroinvertebrates was revealed using the bird exclosure cages (Figure 27). We estimated that birds consumed between 2.50 and 4.93 g m^{-2} benthic invertebrate standing crop biomass in April, May, and June (Decreased abundances of benthic invertebrates from predation outside of cages also negatively affected abundances inside cages via reduced recolonization.

Table 6). Macroinvertebrate biomass was consistently higher inside the cages, indicating that in the absence of predation, the numbers and biomass of macroinvertebrates would have been much higher in ambient conditions if there was lower bird populations and predatory pressure. Decreased abundances of benthic invertebrates from predation outside of cages also negatively affected abundances inside cages via reduced recolonization.

Table 6. Differences in benthic invertebrate biomass (g m^{-2}) between inside and outside of bird exclosure cages from April to June 2020. Differences are assumed to be from bird predation outside of exclosure cages, prior to any potential cage effects.

	Mean	50th	75th	90th

	$(g\ m^{-2})$	$(g\ m^{-2})$	$(g\ m^{-2})$	$(g\ m^{-2})$
Inside	5.68	5.50	8.55	10.72
Outside	3.18	2.32	3.62	6.25
Difference	**2.50**	**3.18**	**4.93**	**4.47**

Biomass was at its lowest in September with a median of 0.32 g m^{-2} inside the cages and 0.12 g m^{-2} outside of the cages (Appendix 6) suggesting that continuous bird predation depleted benthic invertebrate biomass to near zero and birds became food limited or were forced to switch food resources. As discussed earlier, wading shorebirds are mostly limited to foraging at water depths determined by bill and leg length (NDSD Wetlands and Potential Farmington Bay Suitable Shorebird Habitat, Figure 3). NSDS wetland water levels fluctuated throughout the year and water depths dictated when and where shorebirds could successfully feed. In late summer, depths were at their lowest, which allowed shorebirds access to most of the wetted habitat and consequently birds were able to deplete food resources to a greater extent than when water levels were above their bill and leg lengths.

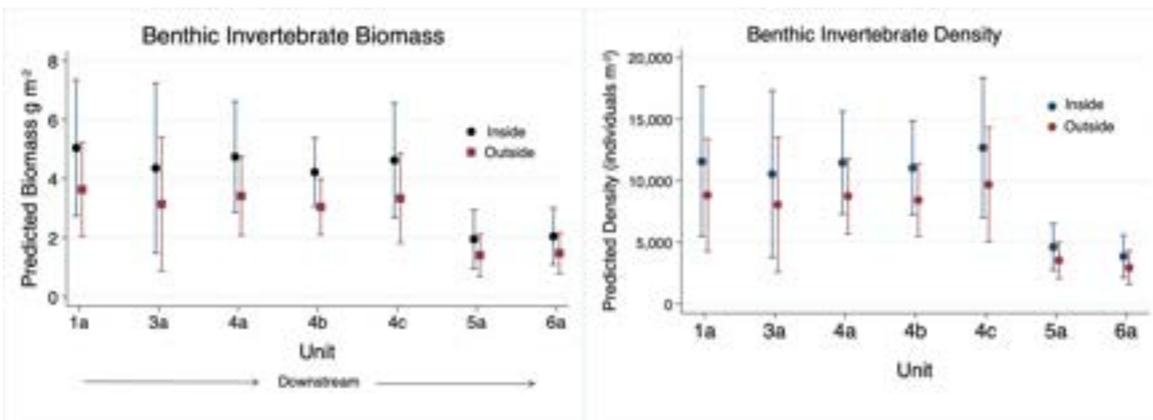


Figure 28. Predicted benthic invertebrate biomass (g m^{-2}) and density (indiviudals m^{-2}) inside and outside of bird exclosure cages between the different sampling units based on negative binomial regressions and marginal predictive analyses. Mean and 95% Cis shown. Ecological reasons for the decline in biomass and density in cages 5a and 6a are being evaluated but could have been due to shallower water that allowed increased bird predation. Regression results in Appendix 1.

Benthic Invertebrate Biomass vs Density

Benthic invertebrate density (individuals m^{-2}) had a significantly strong relationship with biomass (g m^{-2}) as was expected (Figure 30A). The best fit quadratic regression model resulted in an $R^2 = 0.89$ with a decreasing curvilinear relationship and increased variability as densities increased (Figure 29). This trend suggests density- dependent, food- and- habitat- limited growth (biomass), where increased densities resulted in decreasing biomass.

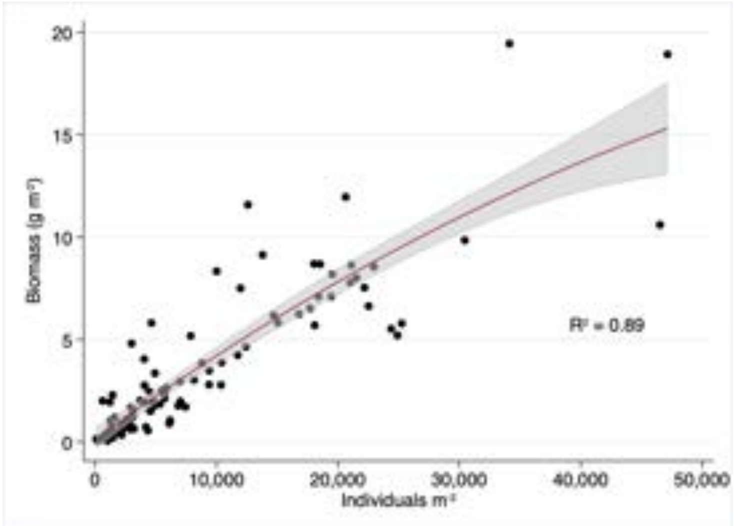
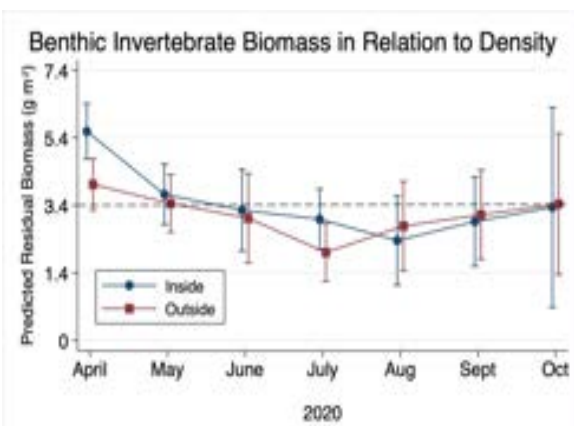


Figure 29. The best-fit quadratic regression line (with 95 Cis) showing relationship between densities (individuals m^{-2}) and biomass (g m^{-2}). Regression model results in Appendix 2.

Regression analysis of the residuals from the quadratic model (Figure 29) showed that there were likely smaller (less biomass) individuals in summer months and larger individual invertebrates in spring and autumn and larger individuals inside the exclosure cages up until about August (Figure 30A). Also, residual analysis showed that there were smaller individuals in Units 4 and 5 compared with the other units (Figure 30B). Our interpretation is in part that; 1) larger *Chironomus* cf. *decorus* gr. dominated the benthic invertebrate assemblage in April and May and smaller *Tanypus neopunctipenis* dominated in abundance later in the season (Figure 23, Figure 24), 2) wading shorebirds selectively captured and fed on the larger invertebrates leaving smaller individual taxa and instars, and 3) wading shorebirds were more abundant in Units 4 and 5 (bird count observational data analysis pending).



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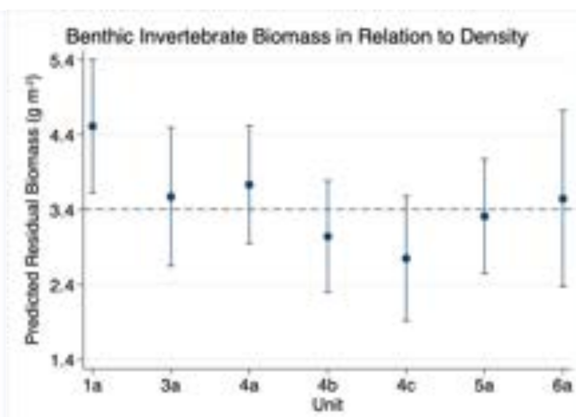


B

Figure 30. Regression models using residuals from quadratic regression model presented in Figure 29 showing the relationship between predicted biomass and months inside and outside of exclosure cages (A) and predicted biomass vs. sampling units (B). Model results are in Appendix 4.

Macroinvertebrate Inventory

Macroinvertebrate ‘bug’ trap samples collected from Unit 3 as part of the macroinvertebrate diversity inventory analysis continue to be taxonomically processed and photographed by River Continuum Concepts (Figure 31). Preliminary results show a diversity of taxa (Table 7) with high abundance of many taxa.

Figure 31. High resolution photograph of the aquatic beetle, Hygrotus bruesi from ‘bug trap’ installed in Unit 3 and retrieved June 26, 2020. Photo by Brett Marshall, River Continuum Concepts, Manhattan, MT.

Table 7. Tentative taxa list from partially processed bug trap deployed in Unit 3and retrieved on June 26, 2020.

Insects		
Ephemeroptera		
	Baetidae	*Callibaetis sp.*
Odonata		
	Coenagrionidae	
Hemiptera		
	Notonectidae (imm/damaged)	
		Notonecta spinosa
	Saldidae	
		Saldula sp.
	Corixidae (imm/damaged)	
		Corisella decolor (M)
		Corisella decolor (F)
		Trichocorixa verticalis (M)
		Trichocorixa verticalis (F)
	Gerridae (imm/damaged)	
	Mesovelidae	
		Mesovelia sp.
Coleoptera		
	Hydrophilidae (imm/damaged)	

		Tropisternus lateralis marginatus
		Hydrophilus triangularis
		Enochrus sp.
	Dytiscidae (imm/damaged)	
		Hygrotus bruesi
		Hygrotus masculinus/salinarius (F, damaged)
Diptera		
	Chironomidae	
		Tanypus
		Chironomus
		Others… pending
	Ephydridae	
		Ephydra (pupae)
Entognathus Hexapoda		*Colembola*
Non-Insects		
		Tricladida
Nematoda		*Nematoda/Nemata*
Annilida		*Oligochaeta*
Acari		*Acari*
Crusteacea		*Cladocera*
Crusteacea		*Copepoda: Cyclopidae*
Crusteacea		*Copepoda: Harpacticoid*
Crusteacea		*Ostracoda*
Crusteacea	Amphipoda	*Hyalella*
Gastropoda	Physidae	*Physa*
Gastropoda	Lymnaeidae	*Lymnaea*

Waterfowl and Shorebirds

Given the difficulties of surveying birds, we estimated that there were roughly between 4,000 (median) to 10,000 (75th percentile) waterfowl and shorebirds using these wetlands with as many as more than 16,500 (Table 8, Figure 32, Figure 33, Appendix 9). Relative abundances of waterfowl and shorebirds varied seasonally with percent shorebirds higher in spring through mid-summer, and a higher percentage of migratory waterfowl occurring in late summer and autumn (Figure 33, Appendix 9). Our findings also show that many shorebirds remain summer residents (Figure 33, Appendix 9). For example, we estimated there were at least 10,000 (median) shorebirds and waterfowl using these wetlands on any given day in August (Appendix 9).

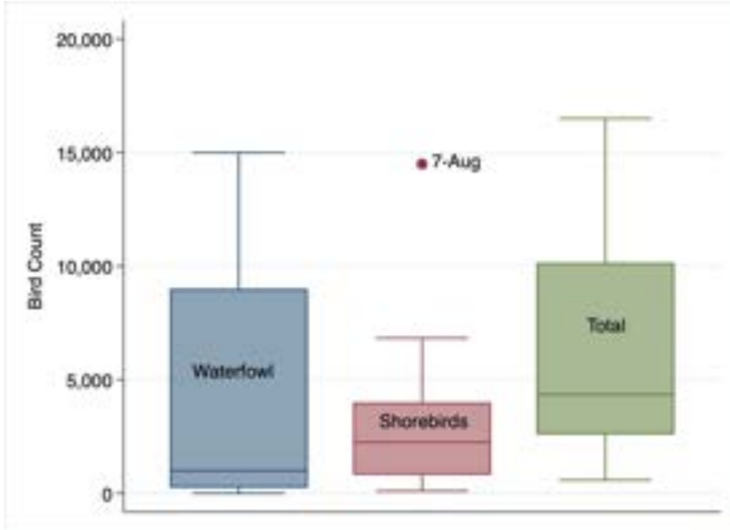


Figure 32. Waterfowl, shorebirds, and total bird counts as of November 10, 2020. Medians, 25th percentiles, 75th percentiles, and ranges.

Early seasonal counts were underestimated because we only counted from the Antelope Island road on the causeway and did not include estimates from walking sandbar to cage 6 and counting from cage. We suggest that March through May counts presented in this report be increased by 2X.

Table 8. N=26 counts

	Waterfowl	Shorebirds	Total
Mean	3,629	2,913	6,542
std.dev.	4,810	2978	5,280
Maximum	15,000	14,500	16,500
Minimum	0	100	580
Median	1,000	2250	4,355
25th percentile	250	816	2,600
75th percentile	9,000	4,000	10,150

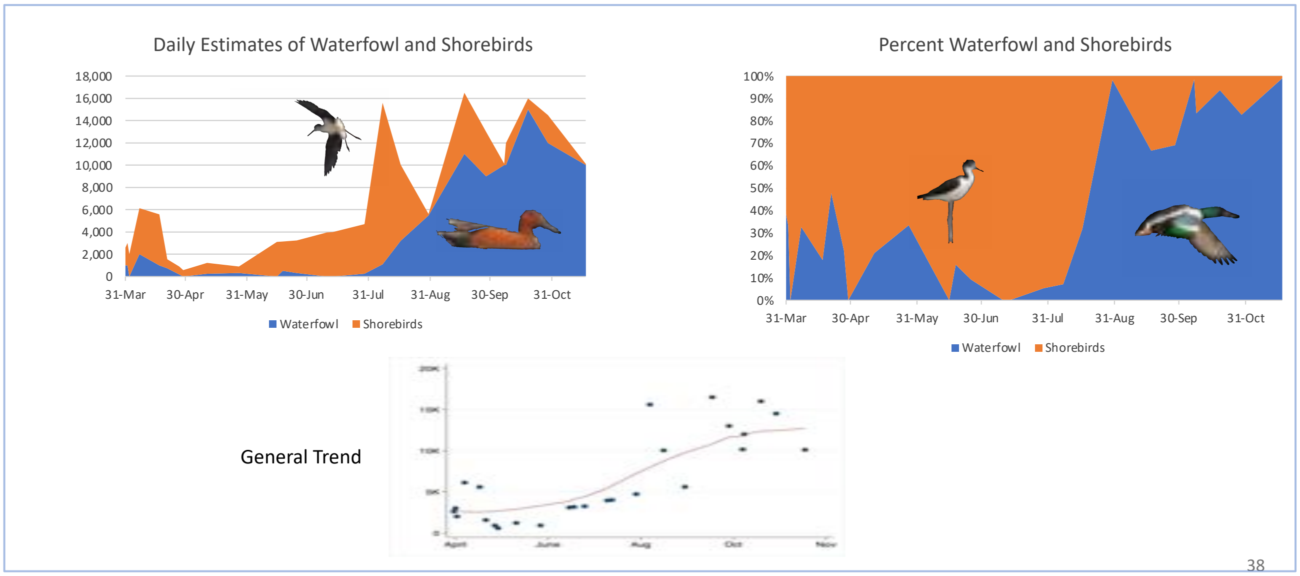


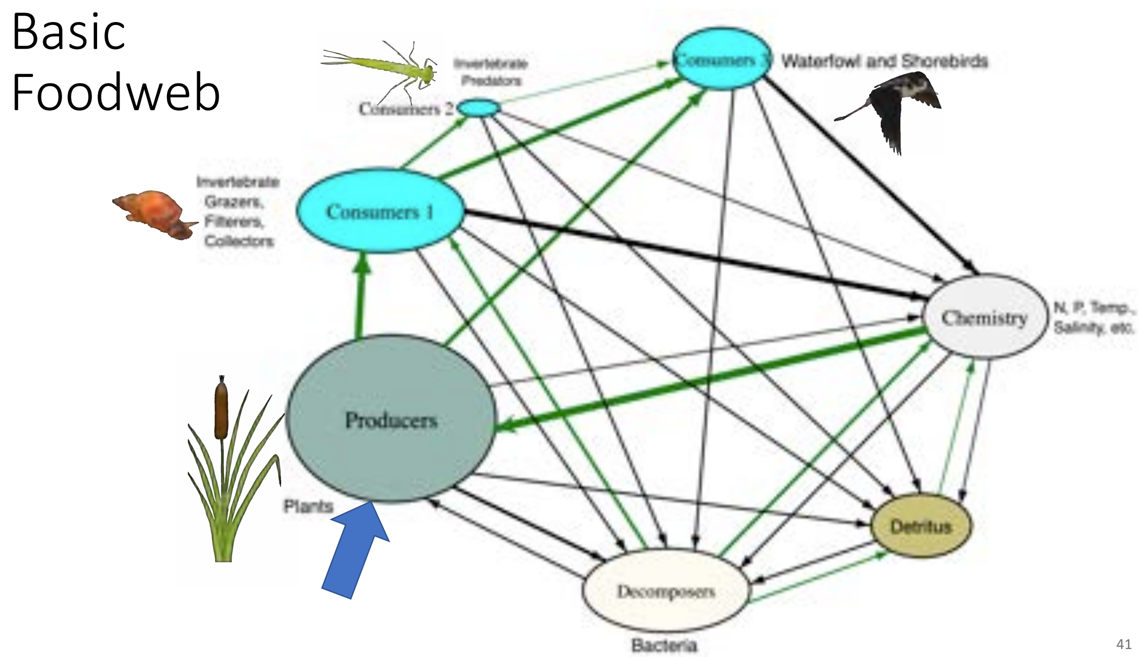
Figure 33. Given the difficulties of surveying birds, we estimated that there were roughly between 4,000 to 14,000 waterfowl and shorebirds using these wetlands with as many as more than 16,000. Relative abundances of waterfowl and shorebirds varied seasonally with percent shorebirds higher in spring through mid-summer, and a higher percentage of migratory waterfowl occurring in late summer and autumn. Our findings also show that many shorebirds remain summer residents. Early season counts were severely underestimated because we only counted from causeway and did not include estimates from walking sandbar to cage 6 and counting from cage. Note: the figure on the top left is a stacked graph.

Wading shorebird benthic invertebrate predation efficiency was limited by water depth and leg length. Seasonal water levels thus dictated locations where wading shorebirds could feed. Wading shorebirds and waterfowl can however, feed on emerging insect pupae and adult insects from the water surface and were observed doings so on most surveying dates. Each bird species has its own unique feeding strategy and limitations. These limitations can allow food resources to recover. For example, water depths were sometimes too great for efficient predation by wading shorebirds or dabbling ducks.

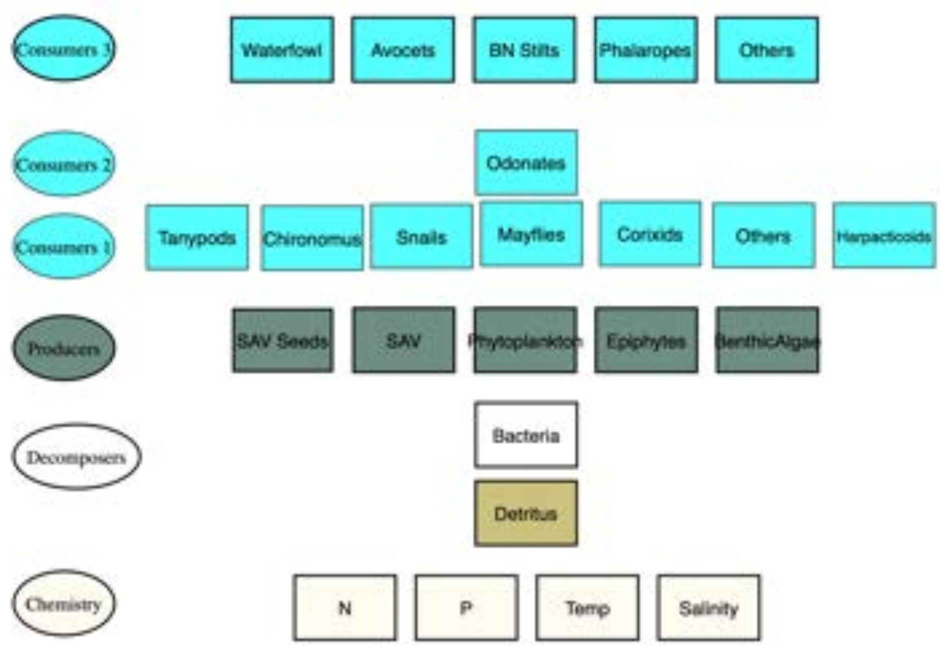
Waterfowl feed much differently than shorebirds and are likely more generalists and can focus their feeding on plants and drupelets. The seasonal abundance of SAV with concomitant seeds and drupelets in autumn contributed to better utilization of the wetlands than during periods in spring and summer with low SAV cover (Hoven et al. 2011, 2014). Thus, there was a major ecosystem shift starting in late summer (Figure 33).

The Basic Food Web

The basic food web of the wetlands is illustrated in Figure 34*A*. Starting with Producers (plants); Consumers 1 are invertebrate grazers, filterers, and collectors that feed on Producers. Consumers 2 are invertebrate predators such as dragonflies and damselflies that feed on Consumers 1. Consumers 3 are waterfowl and shorebirds that feed on Consumers 1 and 2 as well as Producers. Producers are dependent on the chemistry of the wetlands, particularly nitrogen, phosphorus, temperature, and salinity. The decomposers are mostly bacteria and all the groups interact and contribute to detritus. Of course, the food web is much more complicated that illustrated (see Figure 39). Figure 34*B* shows the major 'players' in the food web.



A



B

*Figure 34. The basic food web of NDSD sheetflow wetlands shown in **A**. Starting with Producers, the plants; Consumers 1 are invertebrate grazers, filterers, and collectors that feed on Producers. Consumers 2 are invertebrate predators such as dragonflies and damselflies that feed on Consumers 1. Consumers 3 are waterfowl and shorebirds that feed on Consumers 1 and 2 as well as Producers. Producers are dependent on the chemistry of the wetlands, particularly nitrogen, phosphorus, temperature, and salinity. The decomposers are mostly bacteria and all the groups interact and contribute to detritus. A more detailed description of the 'players' in the food web are in **B**. Of course, the food web is much more complicated that illustrated (see Figure 39). Note: Consumers 1, Harpacticoids should be changed to more generic 'zooplankton'.*

Top-Heavy Mutualistic Positive Feedback Loops

One of our most important food web finding was that the ecology of these wetlands consists of *top-heavy, mutualistic positive feedback loops* between the consumers and the producers. These insights were edified by Herren et al. (2017) in the journal Ecology and cultivated by our research.

The first positive feedback loop in the NDSD wetlands food web, and perhaps the most important, is the mutualism between Consumers 1, benthic invertebrates particularly midge larvae, and the Producers, benthic algae (Figure 35). Midge larvae were by far the most dominant benthic invertebrate in the sheetflow wetlands as measured by density and biomass[2]. Two species of midges dominated, *Chironomus* sp. and *Tanypus neopunctipenis* (see Figure 8). Densities of these midge larvae often were > 15,000 m^{-2} and > 6 mg m^{-2} dry biomass in the early part of the year. Vast amounts of midge biomass are needed to support the thousands of shorebirds that rely on this energetic food resource. The positive mutualistic feedback loop between nutrients, benthic algae, and midge larvae is essential. Herren et al. (2017) showed that as midge larvae densities increase, algal production increases and consequently larval growth rates increase as their densities increase, likely because of the increase in algae. Without this positive feedback in the first loop, far fewer birds would be supported by these wetlands.

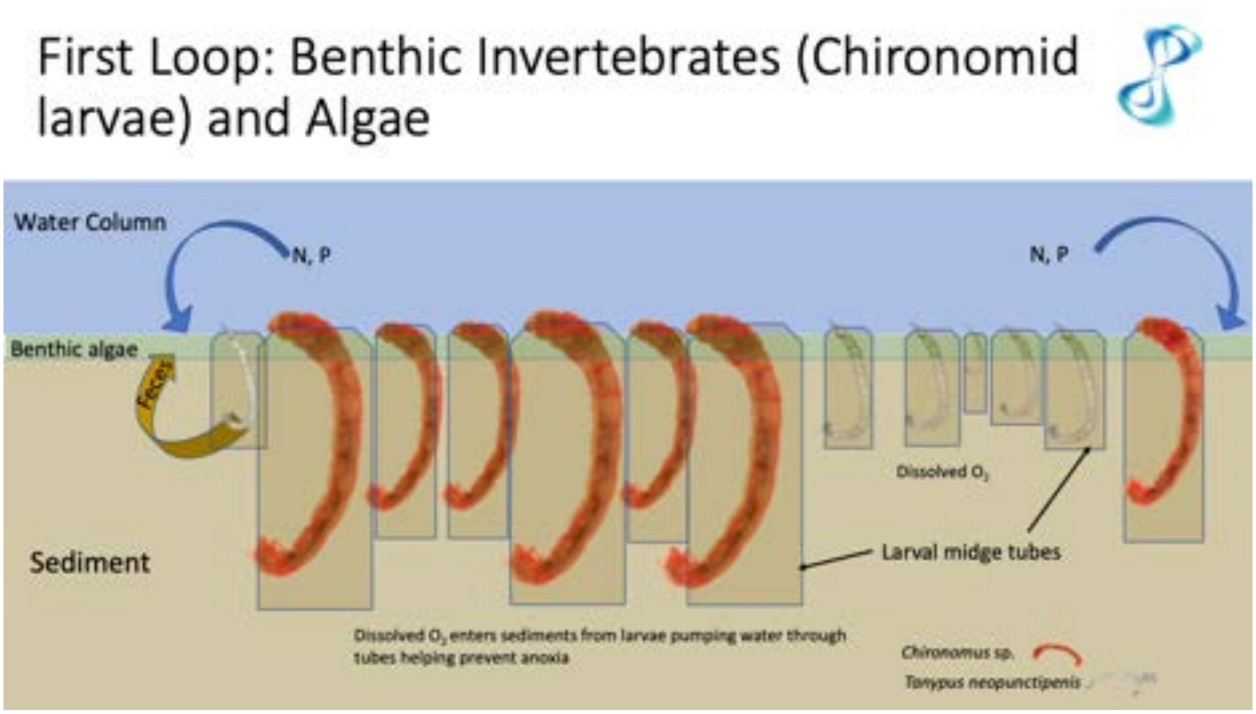


Figure 35. First loop in the positive feedback loop.

[2] Remember oligochaete worms were at such low abundances so as to have minor roles in the functioning of the wetlands (see Oligochaetes, The Case of the Missing Worm).

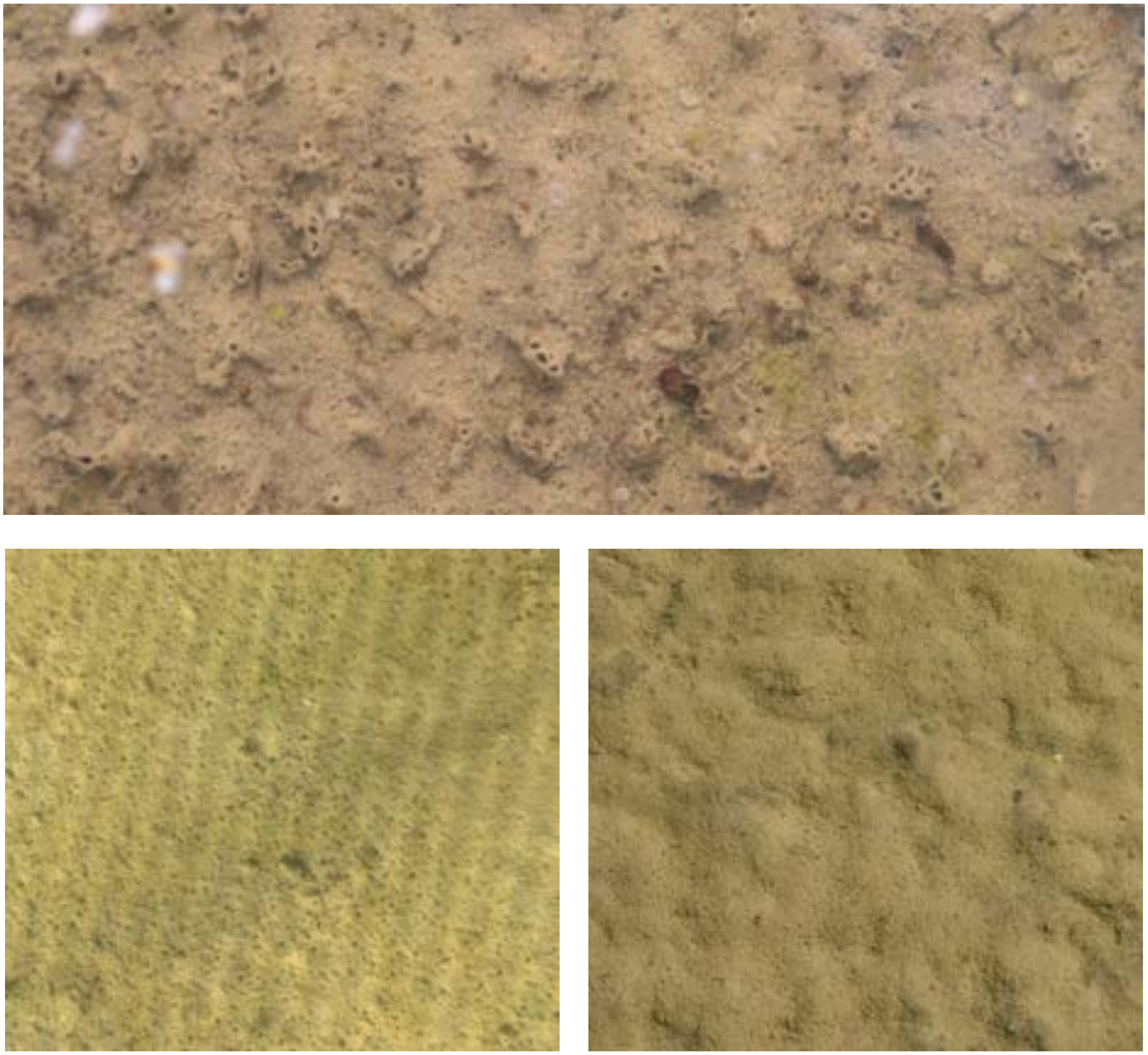


Figure 36. Midge (Chironomidae) larval tubes in benthic sediments of NDSD wetlands. Midge larvae tubes were easily observed in the wetland's soft substrate. Holes in sediment are midge larval tubes shown in the three photos. Inside the bird exclosure cages (lower left photo), larval tubes were uniformly distributed suggesting intraspecific competition for space. Midge larvae tubes were less dense and less uniformly distributed outside of the exclosure cages (lower right photo), where shorebirds ravenously fed on larvae. The top image shows the three-dimensional structure of the tubes, which alter sediment chemistry, structure, and function (Hölker et al. 2015).

The second part of the mutualistic positive feedback loop was comprised of birds, their feces, and nutrients (Figure 37). It appears that waterfowl and shorebirds had more of a top-down effect (top-heavy) affect on the food web, than did nutrients have a bottom-up effect in 2020. A static snapshot of the feedback loop such as that reported in this document for 2020 may not have accounted for the effects of low densities of the food resource in late summer/early autumn on potential bird use in the future.

Bird feces provided several tons of nutrients annually that were directly usable by benthic algae and aquatic vegetation, including soluble reactive phosphorus (SRP) and ammonia (NH_3). Benthic algae were in turn available as food resource to the remaining midge larvae that hadnt been consumed by the birds, which were then available as a food resource for birds. It did however, appear that bird feces were insuffecient for maintaining SRP and NH_3 levels in downstream units (Figure 11, Figure 13) and that primary producers and secondary consumers usurped these available nutrients quicker than they could be replaced. Using bird counts and literature values for defacation rates, we will estimate nutrient additions by the thousands of waterfowl and shorebirds that utilize this wetland.

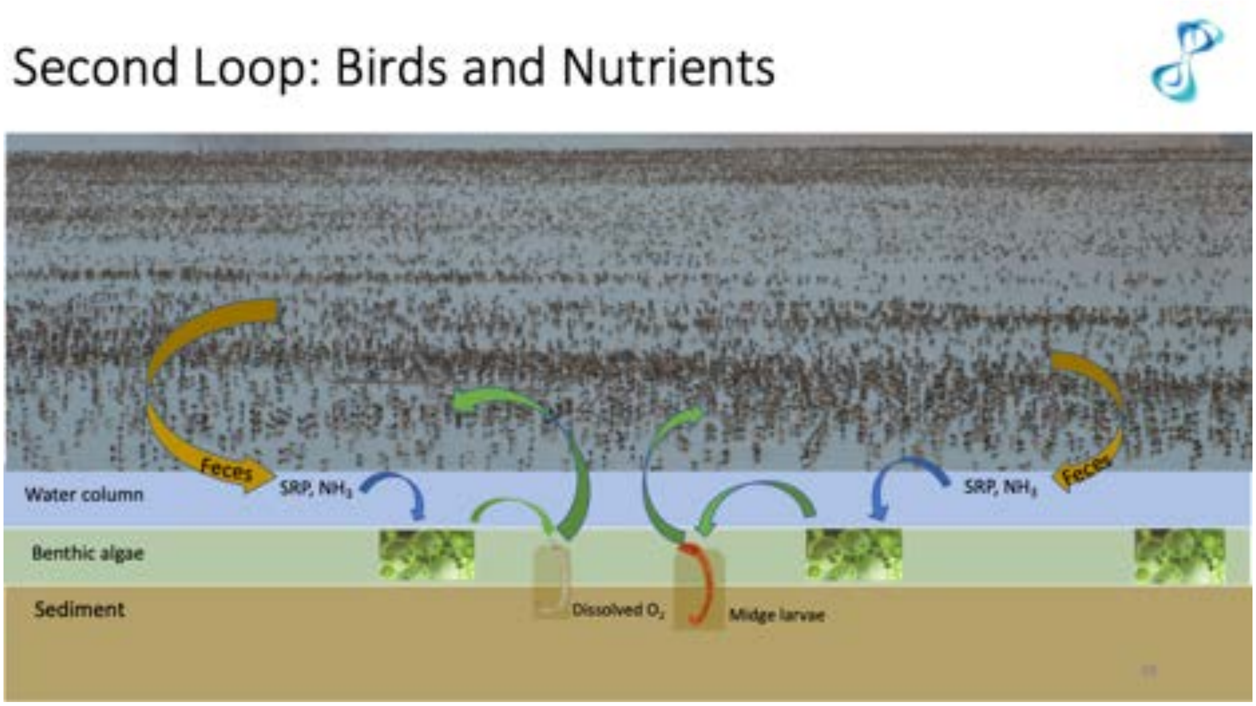


Figure 37. The second part of the Mutualistic Positive Feedback Loop was comprised of birds, their feces, and nutrients. Bird feces provide several tons of nutrients annually that are directly usable by benthic algae and aquatic vegetation, including soluble reactive phosphorus, SRP and ammonia, NH3. Benthic algae are in turn available as food resource to the remaining midge larvae that haven't been consumed by the birds, which are then available as a food resource for birds.

Of course, chironomid larvae are not only a part of the benthic ecology of the wetlands, but aerial adults also provide an important food resource within the food web (Figure 38).

Figure 38. Adult midges swarming along Antelope Island Road adjacent to NDSD sheetflow wetlands in October 2020. The road is popular for bikers who often wear face masks to keep from inhaling a few too many midges. After mating, female midges fly back to the wetlands to deposit their eggs and renew their all-important cycle in the wetland's food web.

Discussion

We have documented major ecological insights in our continuing effort to understand how the NDSD sheetflow wetlands' food web and ecosystem functions. These finding will provide invaluable for guidance and development of food web nutrient models that then can be directly used for managing the wetlands.

The following additional ecological factors need to be considered when making management decisions:

Evapotranspiration

Among other things, evapotranspiration is a function of several variables:

$$ET \int Depth * Airtemp * Watertemp * Wind * Flow * Veg:$$

Where, ET = evapotranspiration; *Depth* = water depth; *Airtemp*= air temperature = *Watertemp* = water temperature; *Wind* = wind speed; *Flow* = water flow velocity; and *Veg* = amount of vegetation cover shading.

All of these variables interact to affect evapotranspiration and are particularly influential during the heat of summer. As water levels drop, more mudflat playa habitat area increases with associated increases in surface temperature adjoining perimeters of remaining wetted wetland. This phenomenon is clearly visible from the satellite image of Farmington Bay shown in Figure 4, where direct solar radiation heats up more and more exposed dry substrates.

Submerged aquatic vegetation and emergent vegetation can reduce ET. For example, emergent vegetation can cool water temperatures via shading and through self-cooling evapotranspiration. Numerous studies have shown that vegetative shading and associated vegetative self-cooling ET actually reduces overall ET; the classic examples occur in urban areas inundated by impermeable asphalt and urbanization. However, some experimental results suggest emergent aquatic vegetation such as phragmites may increase ET (e.g., Milani and Toscano 2013).

Waterfowl and shorebird food resources and habitat are limited in Farmington Bay and all of GSL wetlands, even in summer. Predictions by land managers and scientist working on GSL point to increasing losses (i.e., Great Salt Lake Institute, Westminster College, UT; Great Salt Lake Ecosystem Program, Utah Division of Wildlife Resources; Gardner et al. 2020; Wild Utah Project). Consequently, competition for remaining food resources throughout GSL wetland ecosystems will increase as wetted habitat shrinks, particularly for wading shorebirds, and their population viability, although unmeasured, will be negatively affected.

Desiccation and Freezing

There are no survivability/mortality rate data of the various life stages of any or all of the benthic invertebrate taxa found in NDSD sheetflow wetlands to desiccation. However, some generalizations can be made. For example, many taxa have egg stages that can withstand desiccation and snails can estivate via mucus secretion, although midge larvae, the preferred food item for wading shorebirds, are highly susceptible to desiccation, much more than diapausing egg stages; survivability rates are also unknown.

Freezing depth of benthic substrate increases when water levels (depths) drop in winter. Water is a very good insulator, and a layer of ice can help reduce and prevent benthic substrate from freezing (although anchor ice[3] is an exception). When water is absent, substrate freezing depths increase substantially causing increased mortality of all benthic invertebrate life stages and resulting in reduced population viability. Waterfowl and shorebirds arriving in late winter and early spring with depleted energy reserves from their long migration rely on abundant larger instar macroinvertebrates that have avoided deep ground layer freezing and have slowly grown throughout the winter in the absence of predators. No studies have been conducted on survivability of the various life stages of any of the benthic taxa found in NDSD sheetflow wetlands to freezing or the relation to waterfowl and shorebird population viability.

Macroinvertebrate Metacommunity Dynamics, Viability, and Extinction Risk

Changes in the amount of wetted area in NDSD sheetflow wetlands affects macroinvertebrate metacommunity dynamics and potentially viability. Each macroinvertebrate species within the NDSD sheetflow wetland metacommunity reacts differently to these changes as does the chemistry, algal assemblages, macrophyte, and bird assemblages within the food web. The interactions between these species and the length of time and size of area that may become desiccated or frozen due to management decisions will affect macroinvertebrate metacommunity dynamics and viability. In general, macroinvertebrate metacommunity dynamics in NDSD wetlands are,

1) directly related to recolonization abilities of each species from nearest population,
2) the length of time required to reestablish and become viable populations,
3) each species tolerances to desiccation and freezing at various life history stages, and
4) their vulnerability to predation, etc.

It is well established in the metapopulation and metacommunity dynamics discipline, that as habitats become more and more isolated, metapopulation and metacommunity viability decreases and extinction risk increases.

Also, short-lived, poikilothermic (cold-blooded) benthic invertebrate abundances are stochastic such that annual population variability can be high. For example, midge populations are known to vary by orders of magnitude from year-to-year in Lake Myvatn, where the dominant midge, *Tanytarsus gracilentus* showed cyclic population fluctuation with three peaks occurring during a 20-year period (Einarsson and Örnólfsdóttir 2004). We have also documented large annual variability of the midge population in Utah Lake (Richards et al. 2019, Richards and Miller unpublished data, and personal observations). It is unknown, at this time whether midge or other benthic invertebrate populations in NDSD wetlands were at

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[3] Anchor ice is submerged ice attached or anchored to the bottom of a water body.

peak or trough abundances in 2020. Knowledge of annual variability in these populations is indispensable to the management of timing, level, and duration of NDSD waters entering the wetlands.

Waterfowl and Shorebird Feeding Ecology

Prey availability is a combination of both prey density and vulnerability to capture by predators. Prey vulnerability is affected by characteristics of the predator, prey, and environment (Lantz et al. 2010, Wiens 1984, Sutherland 1996, Gawlik 2002). For example, researchers showed that wading bird density is positively related to both prey size and abundance, although prey size sometimes can be more influential than prey abundance to minimize foraging energy expenditure by the birds (Moser 1986, Trexler et al. 1994, Klassen et al. 2016).

Shorebirds often select smaller sized wetlands for several reasons including security and food resource availability. Decreasing surface area can result in an increase in prey density, and shallower water makes prey more accessible to birds that have bill and leg length limitations that are species dependent (Gawlik 2002, Bancroft et al. 2002, Gawlik and Crozier 2007, Smith et al. 1995, Strong et al. 1997, Arengo and Baldassarre 1999, Ntiamoa-Baidu et al. 1998, Gawlik 2002, Gawlik and Crozier 2007, Lantz et al. 2010, Dimalexis and Pyrovetsi 1997, Kersten et al. 1991, Sorenson et al. 2020). Herring et al (2010) demonstrated that prey availability and hydrological factors regulate populations of wading birds[4] in the Florida Everglades[5] and that bird species vary in their sensitivity to these factors.

Submerged aquatic vegetation (SAV) also has great potential to influence the vulnerability of wading bird prey, yet few studies have examined the relationships between SAV and wading birds' foraging decisions (Sorensen et al. 2020). Vegetation adds structural complexity to the water column, which increases the prey use of these areas when predators are present (Werner et al. 1983), and prey density is often higher in vegetated than in non-vegetated areas (Dvorac and Best 1982, Diehl 1988, Rozas and Odum 1988). Prey may alter their behavior in areas of structural complexity to lower their risk of attack (i.e., by using substrates such as SAV for cover; Charnov et al. 1976).

Studies have shown that prey availability within a habitat is important in determining wading birds' selection of a site for foraging (Ntiamoa-Baidu et al. 1998, Laubhan and Gammonley 2000, Safran et al. 2000, Gawlik 2002, Sorensen et al. 2020). In seasonally fluctuating wetlands such as the Florida Everglades, and NDSD wetlands, habitat conditions change as water recedes through the dry season, consequently wading birds must reassess potential foraging habitat continuously via environmental and social cues, so as to select the most productive patches (Ntiamoa-Baidu et al. 1998, Laubhan and Gammonley 2000, Safran et al. 2000, Gawlik 2002).

"Giving-up density" of prey is the density of prey remaining in a patch at the time that a predator stops foraging within it (Brown 1988) and may have occurred in autumn in NDSD wetlands when wading shorebird abundances were decreasing and macroinvertebrate biomass and densities were lowest (Figure 27, Figure 33).

[4] The idea that prey availability limits populations of wading birds is termed the "prey-availability hypothesis" (Gawlik 2002, Butler 1994, Hafner 1997).

[5] We submit that waterfowl and shorebird densities in NSDS sheetflow wetlands can rival those in Florida's Everglades.

Most waterfowl and shorebird species time their breeding cycle to coincide with maximum food availability (Perrins 1991, Houston 1997, Thomas et al. 2001):

> "The "match-mismatch hypothesis" links reproductive success to annual variability in the temporal and/or spatial overlap between an animal's nutritional needs and its food supply (Cushing 1990, Gawlik 2002, Lantz et al. 2010).The hypothesis assumes that: 1) both the predator and the prey display a certain degree of seasonality; 2) recruitment of the predator is limited by its access to prey during the breeding season; and 3) natural selection favors individuals that match peak food demands (i.e., post migration, reproduction, staging pre migration) with peak food availability. Thus, reproductive success will be greatest when the predator's requirements align with the availability of the prey. Consequently, a mismatch between food requirements and food availability will reduce the predator's reproductive success (Cushing 1990; Durant et al. 2007; Dunn et al. 2011).
>
> However, the "threshold hypothesis" states that the abundance of prey will only affect predator populations when availability of prey is below a certain threshold (Nager et al. 1997). Therefore, the match-mismatch hypothesis encompasses both spatial and temporal accessibility of prey, but the threshold hypothesis suggests the relationship also varies according to the abundance of the prey (Gotceitas el al. 1996; Durant et al. 2007). Durant et al. (2005) modeled trophic interactions of match-mismatch relationships relative to prey abundance in three different ecosystems. They found that changes in prey abundance can reduce or intensify the effects of the mismatch event (Durant et al. 2005)."

All of these intricacies in waterfowl and shorebird feeding ecologies need to be addressed and incorporated into NDSD wetland management options in order to best meet the Clean Water Act and UDWQ's designated beneficial uses directives.

Conclusion

The wetlands in this study were effluent dominated by NSDS wastewater treatment facility's water. In 2020, these wetlands functioned via top-down-dominated, mutualistic, positive feedback loops fueled by nutrients from North Davis Sewer District outflow. Waterfowl and shorebirds consumed large amounts of benthic invertebrate biomass that affected assemblage structure and function and the wetlands were likely seasonally nutrient limited in the farthest downstream units approaching Farmington Bay. We did not observe any cyanobacteria blooms in the wetlands in 2020 and we don't expect them to occur in the future. These wetlands provided important habitat for thousands of waterfowl, shorebirds, and other wildlife dependent on this ecosystem. Any changes in the amount and timing of wetted area in NDSD sheetflow wetlands based on management operations will affect macroinvertebrate metacommunity dynamics and viability as well as waterfowl and shorebird population dynamics. Continued research and development of food web-nutrient dynamics models are imperative to help determine when and for how long changes in NDSD outflow flow levels will affect these wetlands.

Ongoing and Future Research

Data that produced results presented in this report along with continued data from our research and data from scientific literature will now be utilized in food web models that will help manage sheetflow wetlands including the most appropriate uses of NDSD effluent water. These models will be a combination of Joint Species Distribution Models, Bayesian Hierarchical Species Community models, and mechanistic mass-balance food web models linked with spatial Habitat Foraging Capacity models using Ecopath and Ecosim (https://ecopath.org) (see Figure 39 for an example). We are in the early stages of collaboration with scientists/modelers at University of British Columbia that have developed and worked extensively with these models to speed us along in our modelling efforts and to help verify that our model inputs are scientifically justified.

Food web sections in the models will include:

1) Waterfowl and shorebird energy requirements and population dynamics,
2) benthic invertebrates and zooplankton secondary production, ecology, and life history requirements,
3) benthic algae, macrophyte, and phytoplankton primary production, and
4) nutrients and chemistry variables.

Estimated completion of the first round of models is mid-February 2021. These models will also have the ability to link to other models developed by other Farmington Bay researchers, including DWQ. Our goal is to have these models be predictive of future changes to the sheetflow wetland's ecosystem under differing management strategies. It is critical to continue collecting environmental and ecological data from these wetlands throughout 2021 to assure all stakeholders that model outputs are as accurate and precise as possible, do not over-rely on literature-based values, and that these models have enough predictive power to assure managers that their decisions are based on the most relevant scientific data and interpretation.

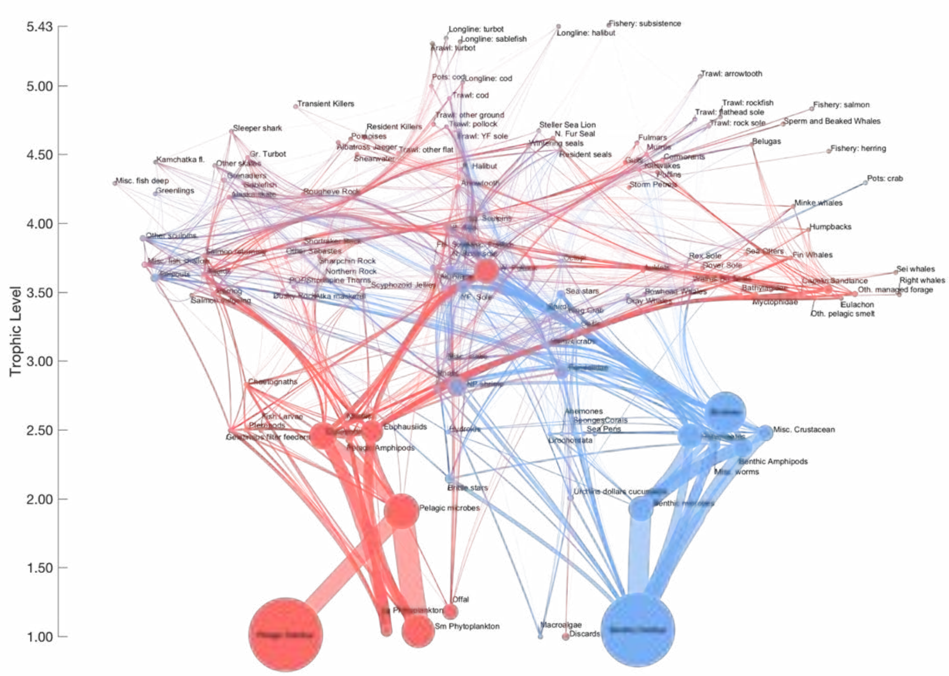

Figure 39. Example of a static-mass balance food web model using Ecopath that can then be used in Ecosim-a dynamic simulation module for policy/management operations exploration. We are in the process of populating an Ecopath model for NDSD sheetflow wetlands. Estimated completion of the first round of models is mid-February 2021. The Ecopath food web model shown in this figure is for the Bering Sea (https://www.integratedecosystemassessment.noaa.gov/regions/alaska/ebs-integrated-modeling).

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Appendices

Appendix 1. Negative bionomial regression results for benthic invertebrate biomass (dry weight g m^{-2}) as a function of inside or outside of bird exlosures, month, and sampling unit.

```
Negative binomial regression                    Number of obs     =        108
                                                Wald chi2(13)     =     171.91
Dispersion           = mean                     Prob > chi2       =     0.0000
Log pseudolikelihood = -228.43894               Pseudo R2         =     0.1018

------------------------------------------------------------------------------
             |               Robust
dryweightgm2 |        IRR   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   inoutcode |
    Outside  |      0.721      0.114   -2.077   0.038         0.529       0.982
             |
       Month |
        May  |      1.329      0.303    1.244   0.213         0.849       2.078
       June  |      0.970      0.325   -0.092   0.927         0.502       1.872
       July  |      0.891      0.200   -0.517   0.605         0.574       1.382
        Aug  |      0.425      0.103   -3.535   0.000         0.265       0.683
       Sept  |      0.125      0.029   -9.076   0.000         0.080       0.196
        Oct  |      0.332      0.170   -2.157   0.031         0.122       0.904
             |
    unitcode |
         3a  |      0.864      0.369   -0.342   0.732         0.374       1.997
         4a  |      0.939      0.272   -0.216   0.829         0.533       1.656
         4b  |      0.837      0.213   -0.697   0.486         0.508       1.380
         4c  |      0.917      0.264   -0.302   0.763         0.521       1.612
         5a  |      0.387      0.130   -2.822   0.005         0.200       0.748
         6a  |      0.405      0.134   -2.733   0.006         0.212       0.775
             |
       _cons |      5.659      1.433    6.844   0.000         3.445       9.295
-------------+----------------------------------------------------------------
    /lnalpha |     -0.976      0.240                         -1.445      -0.506
-------------+----------------------------------------------------------------
       alpha |      0.377      0.090                          0.236       0.603
```

Appendix 2. Quadratic regression of benthic invertebrate biomass (dry weight g m^{-2}) as a function of density (individuals m^{-2}).

```
Stata code: regress dryweightgm2 densityindividualsm2
c.densityindividualsm2#c.densityindividualsm2, noconstant

      Source |       SS           df       MS      Number of obs   =       108
-------------+----------------------------------   F(2, 106)       =    413.05
       Model |  2439.24767         2  1219.62383   Prob > F        =    0.0000
    Residual |  312.992818       106  2.95276243   R-squared       =    0.8863
-------------+----------------------------------   Adj R-squared   =    0.8841
       Total |  2752.24048       108  25.4837082   Root MSE        =    1.7184

---------------------------------------------------------------------------------------
-------------------------
                                dryweightgm2 |      Coef.   Std. Err.      t    P>|t|
[95% Conf. Interval]
---------------------------------------------+-----------------------------------------
-------------------------
                        densityindividualsm2 |      0.000       0.000   14.905    0.000
0.000        0.001
```

```
                                                  |
c.densityindividualsm2#c.densityindividualsm2 |     -0.000      0.000   -2.692   0.008
-0.000      -0.000
```

Appendix 3.

```
regress resid_biomass i.Month i.inoutcode i.Month#i.inoutcode

      Source |       SS           df       MS      Number of obs   =       108
-------------+----------------------------------   F(13, 94)       =      3.59
       Model |  103.834126        13  7.9872405    Prob > F        =    0.0001
    Residual |  208.856094        94  2.22187334   R-squared       =    0.3321
-------------+----------------------------------   Adj R-squared   =    0.2397
       Total |   312.69022       107   2.9223385   Root MSE        =    1.4906

--------------------------------------------------------------------------------
  resid_biomass |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
----------------+---------------------------------------------------------------
          Month |
           May  |     -1.867      0.611   -3.057   0.003        -3.079      -0.654
          June  |     -2.335      0.736   -3.174   0.002        -3.796      -0.874
          July  |     -2.602      0.611   -4.261   0.000        -3.814      -1.389
           Aug  |     -3.232      0.784   -4.120   0.000        -4.789      -1.675
          Sept  |     -2.671      0.784   -3.405   0.001        -4.228      -1.113
           Oct  |     -2.251      1.547   -1.455   0.149        -5.322       0.820
                |
      inoutcode |
        Outside |     -1.573      0.565   -2.786   0.006        -2.695      -0.452
                |
Month#inoutcode |
    May#Outside |      1.304      0.840    1.552   0.124        -0.365       2.973
   June#Outside |      1.333      1.065    1.252   0.214        -0.781       3.447
   July#Outside |      0.592      0.840    0.704   0.483        -1.077       2.260
    Aug#Outside |      2.001      1.099    1.821   0.072        -0.181       4.183
   Sept#Outside |      1.777      1.099    1.617   0.109        -0.405       3.959
    Oct#Outside |      1.673      1.911    0.875   0.384        -2.122       5.467
                |
          _cons |      2.189      0.413    5.295   0.000         1.368       3.010
--------------------------------------------------------------------------------
```

Appendix 4. Linear regression results of residuals from (Appendix 2) of benthic invertebrate biomass as a function of sampling units.

```
Stata code: regress resid_biomass i.unitcode

      Source |       SS           df       MS      Number of obs   =       108
-------------+----------------------------------   F(6, 101)       =      1.73
       Model |  29.0898225         6  4.84830376   Prob > F        =    0.1224
    Residual |  283.600397       101  2.80792473   R-squared       =    0.0930
-------------+----------------------------------   Adj R-squared   =    0.0392
       Total |   312.69022       107   2.9223385   Root MSE        =    1.6757

-----------------------------------------------------------------------------
resid_biom~s |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+---------------------------------------------------------------
    unitcode |
         3a  |     -0.941      0.645   -1.458   0.148        -2.221       0.339
         4a  |     -0.780      0.597   -1.306   0.195        -1.964       0.405
         4b  |     -1.471      0.584   -2.519   0.013        -2.629      -0.313
         4c  |     -1.764      0.613   -2.877   0.005        -2.981      -0.548
         5a  |     -1.200      0.590   -2.033   0.045        -2.371      -0.029
```

```
        6a |     -0.966      0.743   -1.301   0.196       -2.440       0.507
           |
     _cons |      1.113      0.448    2.485   0.015        0.224       2.001
```

Appendix 5. Negative binomial regression results of benthic invertebrate density as a function of inside vs. outside of bird exlosure cages, month, and sampling unit.

```
Stata code: nbreg densityindividualsm2 i.inoutcode i.Month i.unitcode,
dispersion(mean) vce(robust) irr
Negative binomial regression                    Number of obs     =        108
                                                Wald chi2(13)     =     124.78
Dispersion           = mean                     Prob > chi2       =     0.0000
Log pseudolikelihood = -1058.8558               Pseudo R2         =     0.0237

--------------------------------------------------------------------------------------
                     |               Robust
densityindividualsm2 |        IRR   Std. Err.       z    P>|z|      [95% Conf. Interval]
---------------------+----------------------------------------------------------------
           inoutcode |
             Outside |      0.764      0.112   -1.840   0.066        0.574       1.018
                     |
               Month |
                 May |      2.306      0.559    3.446   0.001        1.434       3.710
                June |      2.249      0.783    2.328   0.020        1.137       4.450
                July |      2.020      0.479    2.965   0.003        1.269       3.214
                 Aug |      1.079      0.222    0.372   0.710        0.722       1.614
                Sept |      0.375      0.089   -4.137   0.000        0.235       0.596
                 Oct |      0.451      0.240   -1.496   0.135        0.159       1.281
                     |
            unitcode |
                  3a |      0.913      0.391   -0.214   0.831        0.394       2.111
                  4a |      0.992      0.303   -0.028   0.978        0.545       1.804
                  4b |      0.955      0.293   -0.150   0.881        0.523       1.743
                  4c |      1.098      0.353    0.289   0.772        0.584       2.062
                  5a |      0.400      0.139   -2.641   0.008        0.203       0.790
                  6a |      0.334      0.128   -2.855   0.004        0.157       0.709
                     |
               _cons |   7423.215   2091.060   31.639   0.000     4273.812   12893.437
---------------------+----------------------------------------------------------------
            /lnalpha |     -0.288      0.129                        -0.541      -0.035
---------------------+----------------------------------------------------------------
               alpha |      0.750      0.097                         0.582       0.966
```

Appendix 6. Some descriptive statistics benthic invertebrate biomass by Month inside and outside of bird exclosure cages.

		mean	s.d.	p50	p25	p75
April	Inside	5.94	4.04	5.81	1.56	8.68
	Outside	2.00	1.08	2.01	1.22	2.74
	Total	3.83	3.45	2.49	1.27	5.50
May	Inside	6.79	5.36	7.51	1.77	8.70
	Outside	4.88	5.31	2.69	1.26	7.22
	Total	5.79	5.30	5.79	1.77	8.55
June	Inside	3.09	2.34	2.99	1.02	4.65
	Outside	2.65	1.63	3.03	1.84	3.89
	Total	2.89	1.97	3.03	1.02	4.24

July	Inside	3.01	3.07	1.86	0.29	6.19
	Outside	3.39	3.37	1.81	0.63	5.67
	Total	3.21	3.17	1.86	0.40	5.82
Aug	Inside	1.18	0.58	0.90	0.73	1.77
	Outside	2.01	1.15	1.68	1.51	2.80
	Total	1.59	0.96	1.59	0.73	1.85
Sept	Inside	0.59	0.32	0.65	0.63	0.69
	Outside	0.38	0.12	0.39	0.36	0.40
	Total	0.48	0.25	0.47	0.36	0.65
Oct	Inside	0.07	.	0.07	0.07	0.07
	Outside	1.66	1.40	1.50	0.43	2.63
	Total	1.48	1.42	0.59	0.41	2.52
Nov	Inside	14.26	.	14.26	14.26	14.26
	Outside	1.85	0.51	1.88	1.41	2.30
	Total	4.34	5.57	2.29	1.46	2.30

Appendix 7. Farmington Bay Benthic Invertebrates: Field Sampling and Laboratory Procedures

Version 1.4

Farmington Bay Benthic Invertebrates

Field Sampling and Laboratory Procedures

For
Wasatch Front Water Quality Council Researchers

By
David C. Richards, Ph.D.
OreoHelix Ecological

Last updated: April 14, 2020

Justification

Benthic invertebrates are an unappreciated but crucial component in the ecological health and function of Great Salt Lake wetlands, including Farmington Bay. For example, migratory shorebirds and waterfowl completely depend on these wetlands and the food sources they provide. Benthic invertebrates are one, if not the major, food item in their diets. Without the benthic invertebrate food resource in Great Salt Lake wetlands, migratory bird populations throughout the entire Central Flyway from Mexico to Canada would decline and their viability and survivability would be reduced. Many of these bird species' entire existence depends on these food resources. However, no one has ever measured spatial and temporal variability in benthic invertebrate biomass and production; or determined their role in maintaining GSL wetland ecological health, including their importance to migratory birds in GSL wetlands.

We are measuring secondary production and diversity of benthic invertebrates in approximately 1000-hectare sheetflow wetland in Farmington Bay (Figure 1) in relation to North Davis Sewer District outfall and waterfowl and shorebird predation. Results of this study will help managers to more fully understand the role of benthic invertebrates to the ecology and importance of this sheetflow wetland to migratory birds and also to help guide regulations concerning wetland receiving waters from NDSD outfall.

Figure 40.Location of six study units in Farmington Bay North Davis Sewer District sheetflow wetlands.

Note: It is critically important to properly and consistently label jars and vials

Field Collection

Equipment needed

1. Mini- Surber sampler with 500 μm mesh net (Figure 41)
(If the mini-Surber sampler for some reason is not available, then a D-frame benthic net with 500 μm mesh net will suffice)[6]
2. Plastic tub for elutriating sample
3. Three (3) benthic jars (Figure 42)
4. Garden trowel demarcated to 10 cm depth
5. Tape measure

[6] If for any reason the mini-Surber sampler is not available, then use the D-frame benthic net. Section off a square area in the substrate the width of the net. Dig the net down to 10 cm depth and drag substrate into the net. Process using the same methods as for mini-Surber. Three to five randomly selected net samples composited outside exclosure only. Inside exclosure, mark a square area the same size as mini-Surber 15 by 15 cm and use trowel to scoop sediment into the D-net. Three samples composited inside exclosures. Label jar with additional label "D-net".

Figure 41. Mini-Surber sampler with 500 µm mesh. 15 cm x 15 cm sampling area.

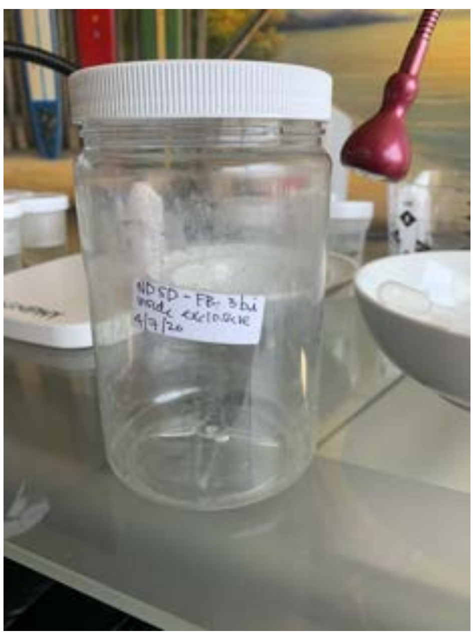


Figure 42. Benthic jars with improper label. Should be NDSD-FB-3-Outside-Biomass, 7 April 2020.

Method

Benthic samples will be collected both inside and outside of the bird exclosures. Additional outside sampling not associated with exclosure cages throughout the season is likely.

Outside Exclosure Biomass

Five (5) randomly selected min-Surber samples should be collected outside of the exclosure and then composited. Randomization accomplished by tossing the min-Surber over the researchers back. The Surber will then be placed such that the area within the Surber is flat on the substrate. Substrate sediment to 10 cm depth should be scooped into the Surber using the trowel. Each sample in the Surber will be inverted and contents placed into the tub 1/3 to ½ filled with water and then sloshed back and forth and gently mixed by hand. Floating and suspended material will then be refiltered into the Surber, more water added to the tub, and filtering repeated three to four times. Filtered sample in the min-Surber will be placed into a properly labeled benthic jar. Any live snails or other invertebrates observed remaining in the tub should be placed into the Surber or benthic jar. Subsequent samples will be collected by tossing the mini-Surber in four different directions. Filtering in tub repeated for each sample and placed into benthic jar so that the jar contains a total of five mini-Surber filtered composited contents. The composited sample in the benthic jar will be properly labeled including, location, date, “Outside”, “Biomass”, date, location, and “5X” to signify 5 composited mini-Surber samples. . Jar should be ¾ filled with local water to help keep invertebrates alive.

Outside Exclosure Taxonomy

The outside exclosure procedure will be repeated and an additional five composited samples will be place into a jar labeled “Outside”, “Taxonomy “, location, date, and “5X” to signify 5 composited mini-Surber samples.

Inside Exclosure

The inside exclosure procedure will be repeated from sediments inside the exclosure except only three (3) min-Surber samples will be composited. This jar will be labeled “Inside”, “Biomass”, location date, and “3X” to signify 3 composited mini-Surber samples. The x-y location of each Surber sample within the exclosures will be recorded using tape measure so that future samples will not be collected in the exact same location within the exclosure to avoid reduced invertebrate biomass bias.

A total of three benthic jars should be made at each site, 1) Inside Biomass, 2) Outside Biomass, and 3) Outside Taxonomy. In addition, jars should be labeled by sample method, either “Surber” or “D-net”. See footnote 1.

Transporting and Storage

Benthic samples will be placed on ice as soon as possible at the vehicle. Samples will be refrigerated at designated location (home, lab). Samples need to be processed as soon as possible so that invertebrates are kept alive and moving. Once the invertebrates die, they are extremely difficult to pick. So far, invertebrates remain alive up to 3- or 4-day, including lab processing time but it is highly recommended to process within 2 days.

Laboratory Processing

Laboratory processing (picking) needs to be completed as soon as possible << 4 days.

Equipment Needed

1.Large tray
2. Pipette
3. Forceps
4. Directional Light
5. Magnifying lamp
6. Small vials for picked invertebrates (Figure 2)
7. Specimen jars for eDNA analysis (Figure 3)
7. Labels (Figure 2)
8. Small dish

Figure 43. Sample jars for inside and outside exclosure biomass samples. Note: Date is properly labeled 7 April 2020.

Figure 44. Specimen jar for eDNA analysis. Note: date is improperly recorded. It should be 7 April 2020.

Method

Contents of benthic jar emptied into large tray and water added to preferred picking level. If water from FB is foul smelling it can be replaced incrementally with tap water without losing any organisms. Evenly distribute contents in the tray. The small dish and one small, properly labeled jar (Figure 43) should be set next to tray. The directional light placed next to one end of the tray so that many of the midge and worm larvae wriggle towards it and are easier to pick. All invertebrates should be picked either using forceps or pipette and placed into small dish, including snails and ostracods. Ostracods are 'clam shrimp' and look like round clams but move quite rapidly in the tray. Go through entire tray and make sure all invertebrates are picked. The more thorough the initial picking, the less time will need to be spent QA/QC. Pickers can do one ¼ section at a time if it helps. Invertebrates in small dish can then be carefully pipetted or forcep picked and placed into small jar (Figure 43). The goal is to have the small jar with as little amount of water as possible. Refrigerate sample jars once tray is completely picked. If it takes more than one day to go through tray, then refrigerate contents of tray overnight. **Do not freeze any samples**. Schedule picking so that total pick time is less than 2 days/sample so that invertebrates do not die and become difficult to find in tray. Save thoroughly picked residual contents for Dr. Richards to QA/QC in the benthic jar. Notify either Frank or Hanna when finished so they can pick up and deliver to Dr. Richards.

Blotted Wet Weights and Oven Dried Weights

Contents of vials labeled "inside" and "outside" "Biomass" will be sorted into lowest practical taxon and then blotted with paper towels and weighed to the nearest 1 mg (blotted wet weight BWW) on tarried aluminum foil trays. Contents on foil trays will then be oven dried at 220 ^{0}F for 4 hours and reweighed (dry weight biomass). BWW and dry weight biomass will be recorded on spreadsheet.

Microscopy Taxonomy and eDNA Taxonomy

Benthic jars (Figure 42) labeled "Taxonomy" will be processed similarly to inside and outside biomass samples. Taxonomy jars will also be delivered to Dr. Richards for processing. Individual taxa from sample jars will be counted to lowest practical taxon and grouped into size classes when appropriate. Recorded. All counted organisms will then be put into properly labeled specimen jar (Figure 44) filled with distilled water and then with one change of distilled water to remove most of eDNA from remaining FB water. Organisms in specimen jar will then be blended using a portable electric wisk until most organisms are crushed. eDNA will then be extracted from the water in the specimen jar using extraction equipment provided by our eDNA contractor, Jonah Ventures. eDNA samples will then be shipped in bulk to Jonah Ventures as soon as possible. Electronic wisk will be cleaned in bleach and triple rinsed in distilled water prior to each eDNA extraction. Bleach destroys DNA and must be completely removed.

As quality control for eDNA taxonomy, some samples pre-blending will be sent to River Continuum Concepts in Manhattan, MT for microscopy taxonomy.

Note: It is critically important to properly and consistently label jars and vials

Appendix 8. Quick Guide to Benthic Invertebrates Likely to be Encountered at the Farmington Bay Bird Exclosure Studies

Quick Guide to Benthic Invertebrates Likely to be Encountered at the Farmington Bay Bird Exclosure Studies

Technical Memo To:
Wasatch Front Water Quality Council
Salt Lake City, UT
By:
David C. Richards, Ph.D.

OreoHelix

OreoHelix Consulting
Vineyard, UT 84058
email: oreohelix@icloud.com
phone: 406.580.7816

May 12, 2020

Most of our samples will be from flowing sheetflow wetlands where the bird exclosure cages are located. Here are images of most of the benthic invertebrate taxa that we are likely to encounter while picking the samples.

Order: Diptera (True flies)

Family: Ephydridae (Shore fly, brine fly)

Figure 45. Ephydrid larvae

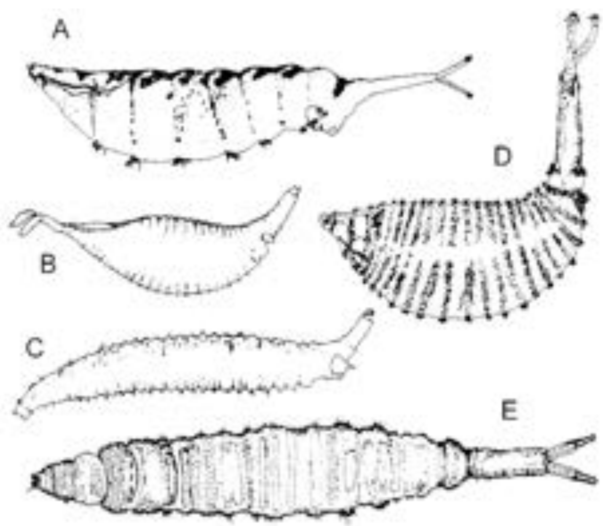


Figure 46. Ephydrid larvae and pupae

Figure 47.Ephydrid pupa

Family: Chironomidae

Figure 48. Chironomus *sp. larvae (left;)* Chironomus *sp. larva (right bottom) and pupa (right top)*

Family: Tanypodidae

Figure 49. Tanypodidae larva

Order: Ostracoda (seed shrimp)

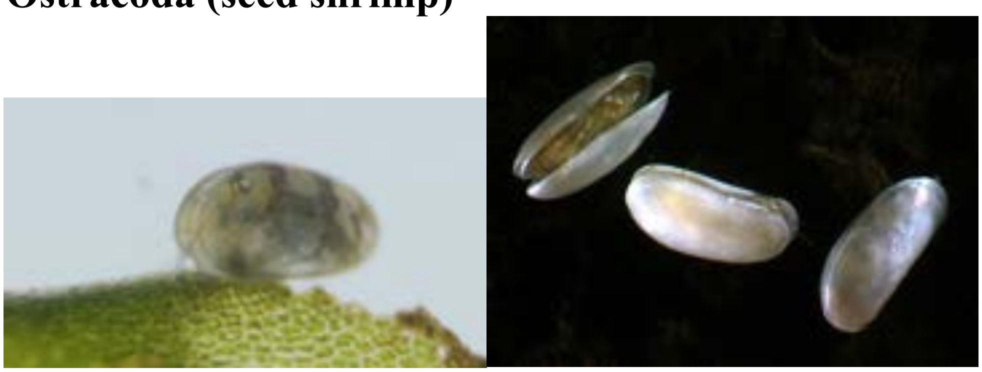


Figure 50. Ostracods

Order Hemiptera (True bugs)

Family: Corixidae (Water boatmen)

Figure 51. Corixids

Figure 52. Trichocorixa *sp.*

Order: Anostraca

Family: Artemiidae (Brine shrimp)

Figure 53. Artemia *sp. nauplii*

Figure 54. Artemia *sp. adult*

Order: Amphipoda

Families: Gammaridae and Hyalellidae (Scuds)

Figure 55. Hyallela *sp.(left) and* Gammarus *sp.(right)*

Order: Odonata

Family: Zygoptera (Damselflies)

Figure 56. Zygoptera larvae

Family: Anisoptera (Dragonflies)

Figure 57. Anisoptera larvae (dragonfly larvae)

Order: Gastropoda (Snails)

Families: Lymnaeidae and Physidae

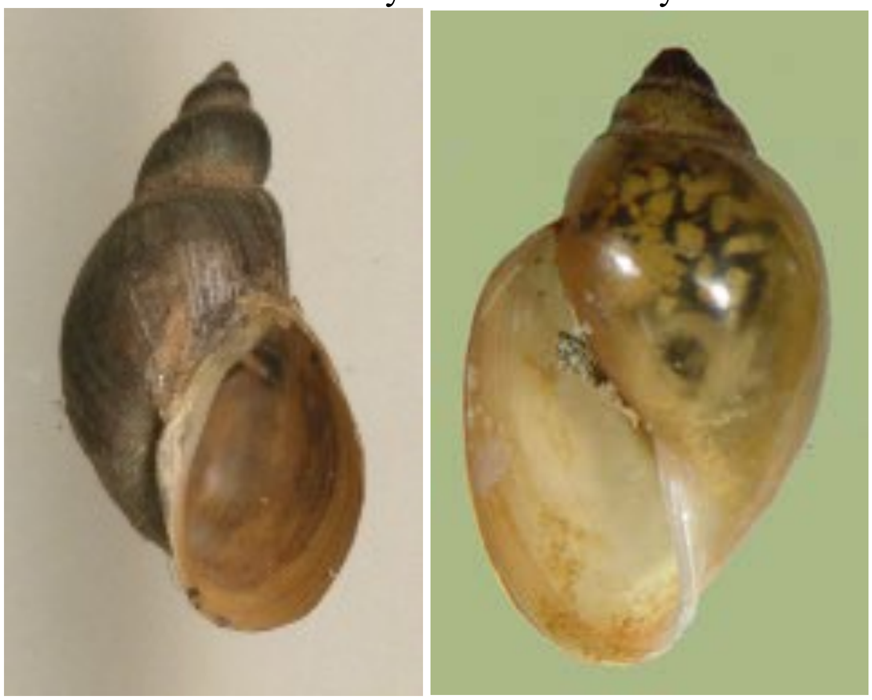


Figure 58. Lymnaeidae (left), Physidae (right)

Appendix 9. Descriptive statistics of bird counts by month.

March	Waterfowl	Shorebirds	Total
Mean	1000	1600	2600
Std.Dev.	.	.	.
N	1	1	1
Maximum	1000	1600	2600
Minimum	1000	1600	2600
Median	1000	1600	2600
25th	1000	1600	2600
75th	1000	1600	2600
April	**Waterfowl**	**Shorebirds**	**Total**
Mean	707.1429	2113.714	2820.857
Std.Dev.	719.0437	1641.571	2216.939
N	7	7	7
Maximum	2000	4580	6120
Minimum	0	580	580
Median	750	2000	2000
25th	0	700	900
75th	1000	4120	5580
May	**Waterfowl**	**Shorebirds**	**Total**
Mean	280	782.5	1062.5
Std.Dev.	35.35534	246.7803	211.4249
N	2	2	2
Maximum	305	957	1212
Minimum	255	608	913
Median	280	782.5	1062.5
25th	255	608	913
75th	305	957	1212
June	**Waterfowl**	**Shorebirds**	**Total**
Mean	266.6667	2896.667	3163.333
Std.Dev.	251.6611	228.1082	70.94599
N	3	3	3
Maximum	500	3100	3240
Minimum	0	2650	3100
Median	300	2940	3150
25th	0	2650	3100
75th	500	3100	3240
July	**Waterfowl**	**Shorebirds**	**Total**
Mean	83.33333	4136.667	4220

Std.Dev.	144.3376	281.1287	425.0882
N	3	3	3
Maximum	250	4460	4710
Minimum	0	3950	3950
Median	0	4000	4000
25th	0	3950	3950
75th	250	4460	4710
August	**Waterfowl**	**Shorebirds**	**Total**
Mean	3266.667	7143.333	10410
Std.Dev.	2200.757	7205.112	5010.818
N	3	3	3
Maximum	5500	14500	15600
Minimum	1100	100	5600
Median	3200	6830	10030
25th	1100	100	5600
75th	5500	14500	15600
September	**Waterfowl**	**Shorebirds**	**Total**
Mean	10000	4750	14750
Std.Dev.	1414.214	1060.66	2474.874
N	2	2	2
Maximum	11000	5500	16500
Minimum	9000	4000	13000
Median	10000	4750	14750
25th	9000	4000	13000
75th	11000	5500	16500
October	**Waterfowl**	**Shorebirds**	**Total**
Mean	11750	1412.5	13162.5
Std.Dev.	2362.908	1047.517	2599.159
N	4	4	4
Maximum	15000	2500	16000
Minimum	10000	150	10150
Median	11000	1500	13250
25th	10000	575	11075
75th	13500	2250	15250
November	**Waterfowl**	**Shorebirds**	**Total**
Mean	10000	100	10100
Std.Dev.	.	.	.
N	1	1	1

Maximum	10000	100	10100
Minimum	10000	100	10100
Median	10000	100	10100
25th	10000	100	10100
75th	10000	100	10100
Total	**Waterfowl**	**Shorebirds**	**Total**
Mean	3629.231	2913.115	6542.346
Std.Dev.	4810.026	2978.979	5280.388
N	26	26	26
Maximum	15000	14500	16500
Minimum	0	100	580
Median	1000	2250	4355
25th	250	816	2600
75th	9000	4000	10150

Appendix 10. Additional information on the importance of midges to ecosystem function.

Midges

Midges (chironomids) are a major link between sediment chemistry, water column chemistry, nutrient cycling, benthic algae, phytoplankton, within the NDSD sheetflow wetland food web. including waterfowl and shorebirds. Midge larvae (Family Chironomidae; Class Insecta) dominated the wetland benthic ecosystem and often comprised 80-90% of the benthic invertebrate biomass. By their sheer volume, biomass, secondary production, and ecology; midge larvae were the benthic/sediment ecosystem engineers responsible for much of the NDSD's sheetflow wetland benthic/sediment function and interaction with the water column.

Adult midges also transfer energy and nutrients out of the wetlands into surrounding wetlands after larval pupation and adults become airborne. Midge swarms along the shoreline of these wetlands are often intense with tens of thousands of adults participating in their mating rituals. The following two videos show such swarms along shoreline habitat:

https://www.youtube.com/watch?v=vVSgmNQS9YI
and
https://youtu.be/aE4nThbiY6s

Adult midges also rest in shoreline vegetation between mating (*Figure 59*) and before females release eggs back into the lake.

Figure 59. Adult male midge (Chironomidae) resting on a wild iris in wetlands along the eastern shore of Utah Lake, July 2019.

Although midge densities and secondary production are high in NDSD sheetflow wetlands, they are and are nothing compared to densities and swarms that can occur in Lake Myvatn, Iceland[7].

Figure 60. Adult midge swarm at Farmington Bay, Great Salt Lake wetland ponds on souther end of Bay. Swarms appear to be dark funnel clouds along the wetland horizon and are not controlled burning.

The following video shows a typical midge swarm in Lake Myvatn:

https://www.youtube.com/watch?v=E0BhQm27RA4.

It has become clear that several dominant benthic taxa, primarily chironomids (midges), can alter benthic ecosystem function and play a key role in the timing and intensity of cyanoHABs in lake ecosystems. However, this relationship has received very little attention, particularly in Great Salt Lake wetlands. In the following section, we discuss our latest literature findings on just how important midge larvae can be to benthic ecosystem functions, including cyanoHABs in Utah Lake.

Substrate Stabilization and Structure, Net Ecosystem Production, and cyanoHABs

Larval midge tubes are constructed from silk similar to the kind of silk produced by spiders, which has very strong tensile strength and ductility. Midge larvae also produce connecting networks of silk that stabilizes the substrate and provides three-dimensional structure to the sediment (Olafsson and Paterson 2004, H€olker et al. 2015). Midge larvae can reach very high densities in NDSD sheetflow wetlands, which certainly helps stabilize the substrate and increases structure (Figure 61).

7 Lake Myvatn literally translates to Midge Lake.

Figure 61. Thousands of different midge larval instar tubes in Provo Bay, Utah Lake, similar to what we have shown in the wetlands of FB. These larvae help stabilize the easily disturbed substrate, provide three-dimensional structure, and the larvae actively oxygenate the sediments including Fe near the sediment water boundary layer. Tubes are likely either Chironomus sp. or Tanypus sp. or both. This photo was taken during a low water year when water levels were shallow enough that large insectivorous fish were excluded, and predation was reduced allowing midge populations to maintain high densities and to continue to provide valuable ecosystem services other than just as fish food.

Midge larval tubes increase sediment shear strength subsequently reducing resuspension and turbidity. Ólafsson and Paterson (2004) documented that *Tanytarsus gracilentus* (midge) larvae in Lake Myvatn, Iceland modified the surface sediment by tube building and showed that shear strength of the sediment surface, and hence resistance to erosion, increased significantly with increased densities of *T. gracilentus* larvae (Phillips et al. 2019).

Sediment stabilization is critical because among other things, sediments and nutrients are easily suspended and affect turbidity and nutrient availability, which often favors cyanoHABs. Midge larval tubes provide three-dimensional structure that also increases habitat for small microorganisms and algae. By providing stable substrate for algae, larval midge tubes indirectly increase gross primary production (GPP) in the sediment, although by consuming algae, midges may inhibit GPP. Midge larvae can also stimulate microbial respiration (RESP) by oxygenating the sediment. (Phillips et al. 2019, Holker et al. 2015). Therefore, the overall effect of midge larvae on net ecosystem production (NEP) depends on the balance between their effects on GPP and RESP, which is also affected by light conditions (Phillips et al. 2019) (*Figure 62*).

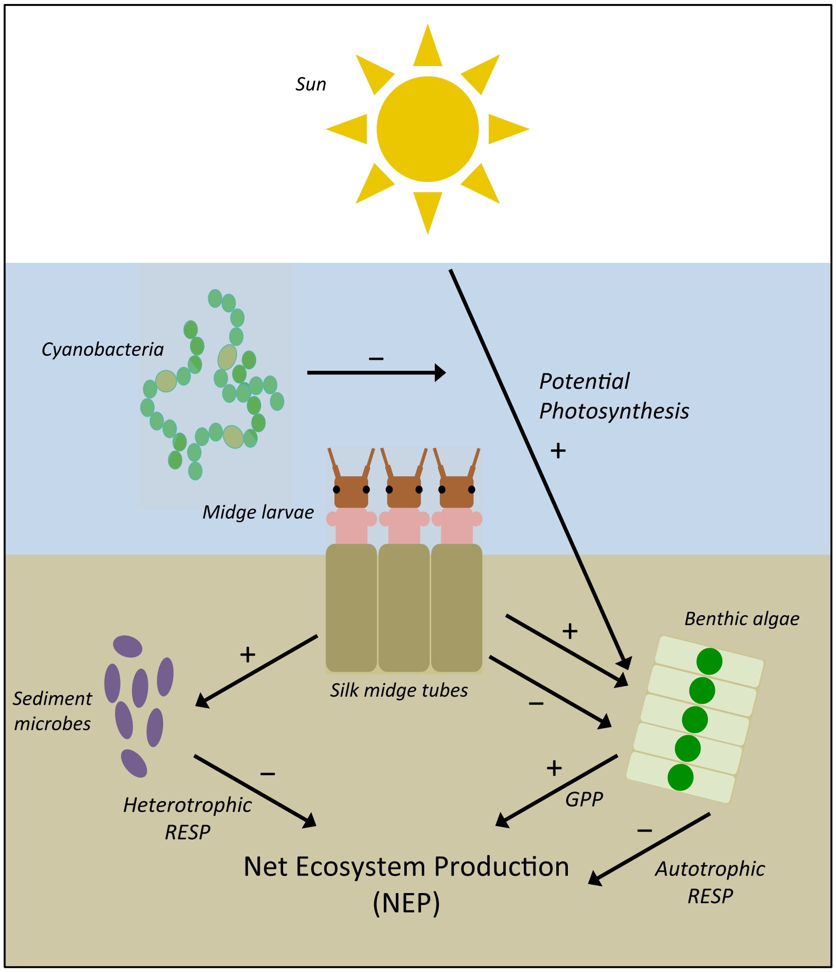


Figure 62, Midge larvae alter benthic ecosystem function. This figure and caption were taken from Philipps et al. 2019. "Midges can alter benthic ecosystem function. Larval midges build silk tubes that provide a substrate for algal growth and increase gross primary production (GPP) in the sediment. However, midges may inhibit GPP through consumption of algae. Furthermore, midges can stimulate microbial respiration (RESP) by oxygenating the sediment. Gross primary production and RESP have opposite effects on net ecosystem production (NEP), so the effect of midges on NEP depends on the balance between their effects on GPP and RESP. We hypothesized that light mediates this balance, because the positive effects of midges on GPP would decline as photosynthesis became more limited by light. Episodic cyanobacterial blooms have a negative effect on benthic light levels, which could result in spatiotemporal variation in the net effects of midges on benthic production."

Midge larvae and cyanoHABs

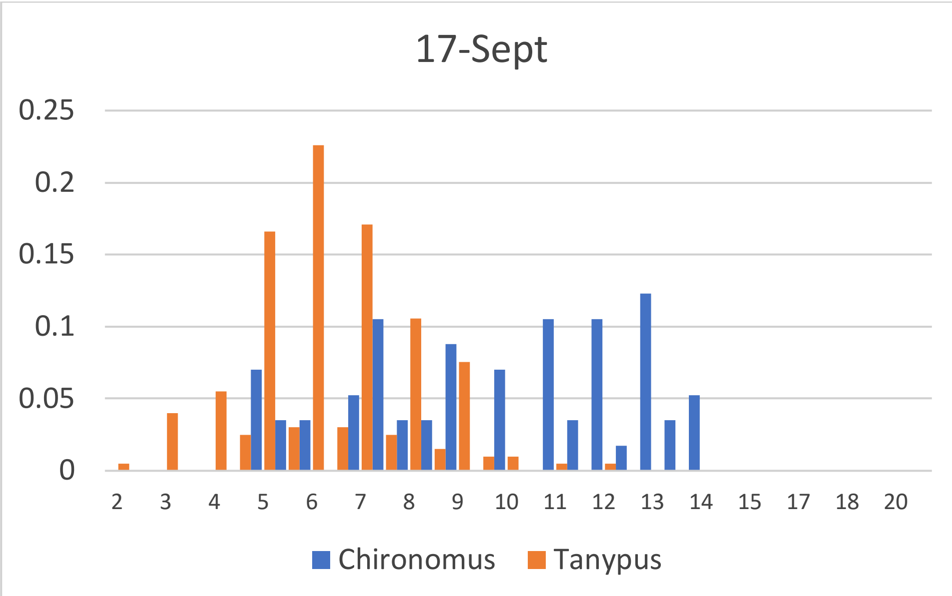
Einarsson and Örnólfsdóttir (2004) also reported that intense cyanoHABs blooms (*Aphanizomenon flos-aquae*) always occurred in years of low chironomid populations but sometimes developed in other years in Lake Myvatn. Einarsson and Örnólfsdóttir (2004) also suggested that cyclic patterns of midges were not likely due to climate. *Tanytarsus gracilentus* in Lake Myvatn showed cyclic population fluctuation with three peaks occurring during a 20-year period. Body size of *T. gracilentus* fluctuated with population size but in an opposite fashion and with a time lag in Lake Myvatn. *T. gracilentus* body size and abundance and predator abundance in Lake Myvatn suggested that the population fluctuations were driven by interaction with resources and not by predator-prey interactions (Einarsson et al. 2002). However, there are only two major predacious fish in Lake Myvatn, three-spined stickleback (*Gasterosteus aculeatus*) and Arctic charr (*Salvilinus alpinus*) (Einarsson et al. 2004), whereas there are several bird species that number in the thousands in NDSD wetlands that readily consume midges.

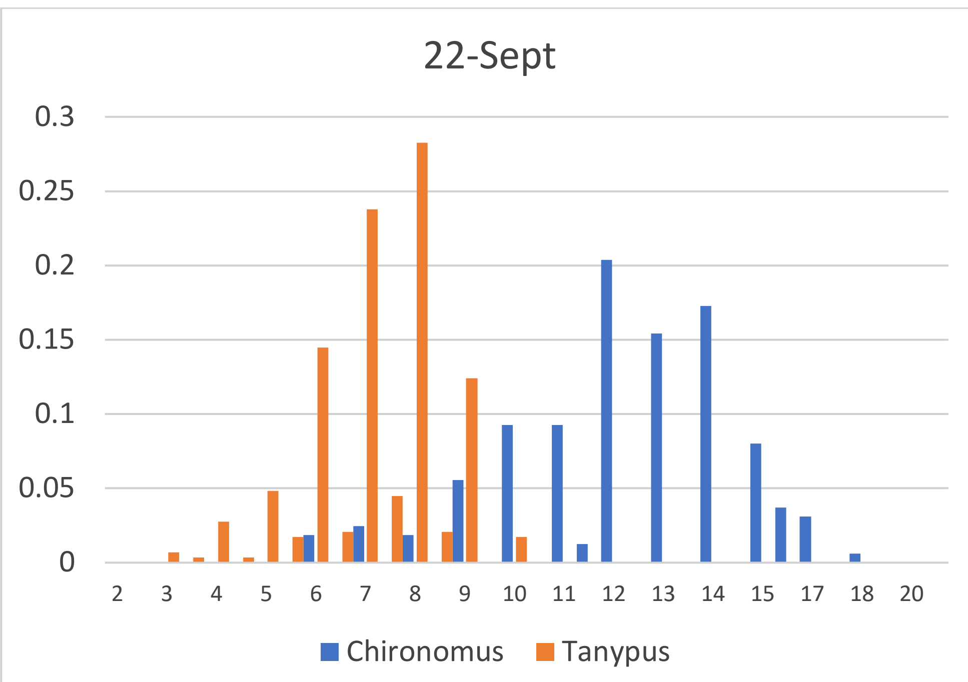
We agree with the midge researchers on Lake Myvatn that the underlying mechanisms for midge cycles are not fully understood and that further investigation is required and that by sheer abundance, midges may be one of the major regulating factors in the long-term dynamics of Lake Myvatn and Great Salt Lake wetlands ecosystems. We also agree with our Icelandic colleagues that "for effective conservation, the only sound strategy seems to be to avoid interfering with the basic components of the ecosystem" (Phillips et al. 2019).

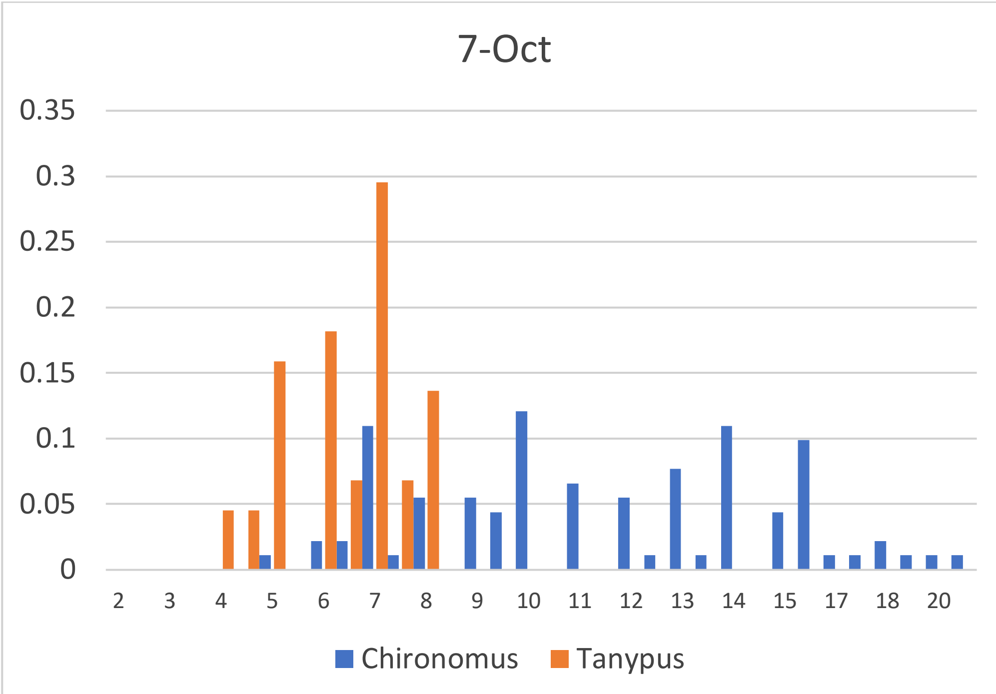
The effects of midge larval on ecosystem respiration (RESP) and GPP vary seasonally with greater effects in summer during increased temperatures. Baranov et al. (2016) showed that RESP in sediments with and without chironomids did not differ at 5^0 C, but at 30^0 C sediment respiration in microcosms with 2000 chironomid larvae per m^2 was 4.9 times higher than in uninhabited sediments. This is a somewhat lower density of larvae than what we typically find in NDSD wetlands and compared to their results suggest that midge larval effects on RESP may be higher in Great Salt Lake wetlands.

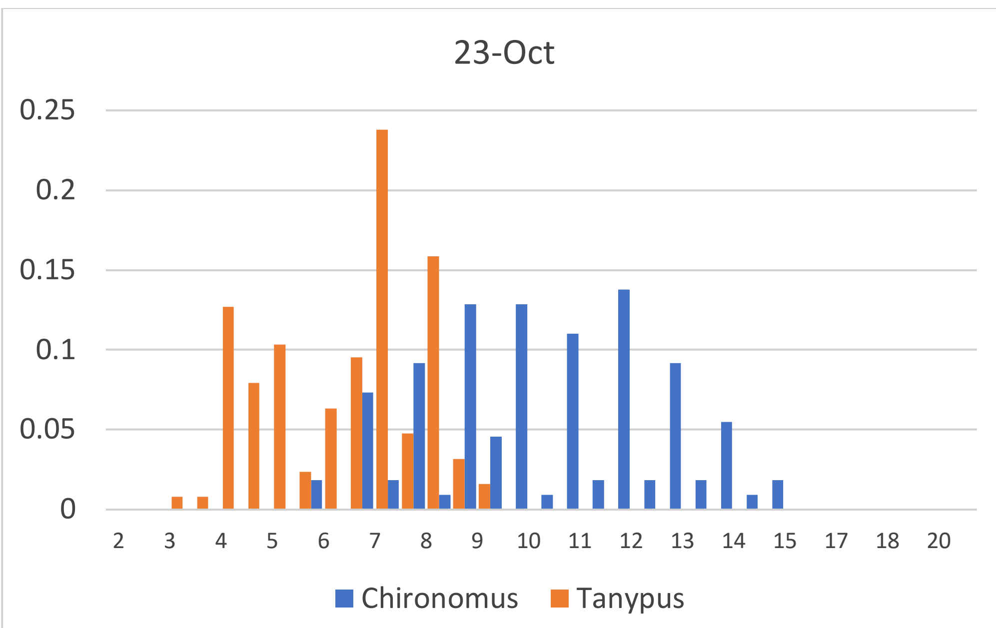
Warm summer water temperatures result in faster midge larval development, shorter life cycles, additional generations per year and higher reproduction rates—all resulting in higher larval densities and intensified ecosystem effects (Hamburger et al. 1995; Eggermont and Heiri 2012). With large densities, especially in eutrophic water bodies with warm water, midge larvae burrowing, and ventilation activities can dramatically impact freshwater biogeochemistry (Morad et al. 2010). For example, in shallow Lake Muggelsse in Germany (mean depth 5 m, relatively similar to Utah Lake mean depth) a volume equivalent to the total water column of the lake is pumped by chironomids through their burrows, once a week (Morad et al. 2010). This rate is likely similar to NDSD wetlands. That is, during certain times of year when midge larvae are at relatively high densities and are active, they can pump the entire water column of the wetlands through the sediments, perhaps weekly or less. Baranov et la. (2016) concluded that high densities of chironomids in shallow lakes can significantly intensify sediment respiration, especially in warm and well-oxygenated systems. This effect is most pronounced in shallow, non-stratified lakes such as NDSD sheetflow wetlands.

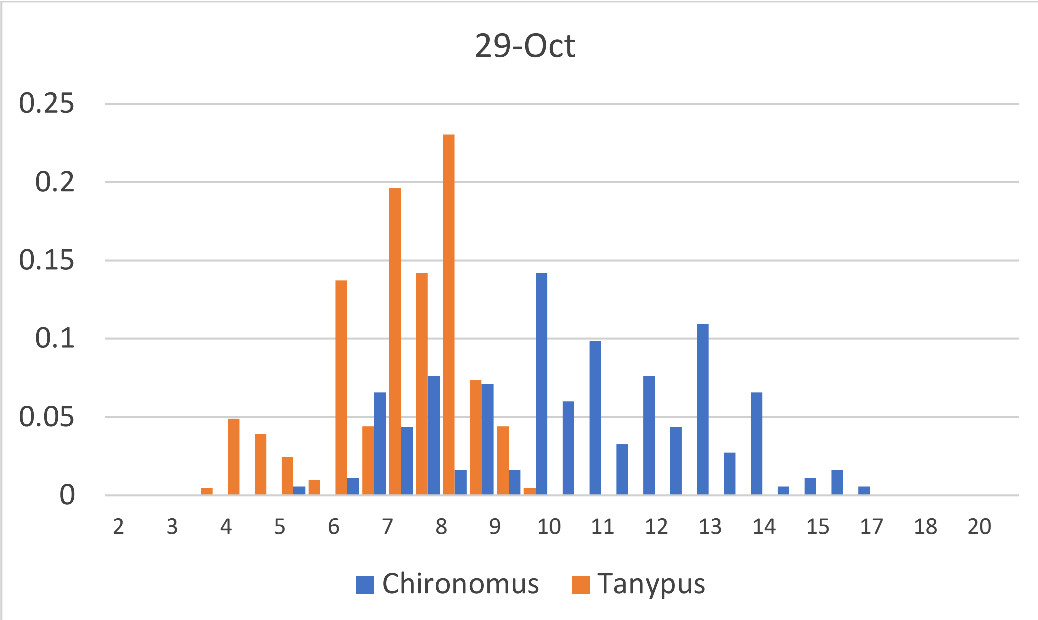
Appendix 11. Preliminary analysis of Chironomus c.f decolor gr. and Tanypus neopunctipenis size classes

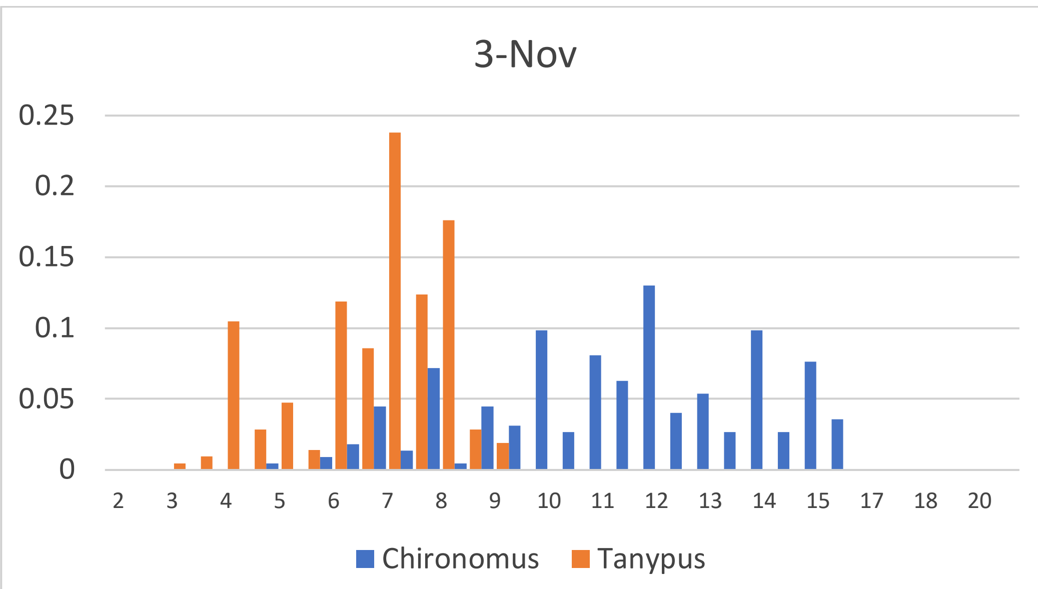





7-Oct
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2 3 4 5 6 7 8 9 10 11 12 13 14 15 17 18 20
Chironomus
Tanypus


23-Oct
0.25
0.2
0.15
0.1
0.05
0
2 3 4 5 6 7 8 9 10 11 12 13 14 15 17 18 20
Chironomus
Tanypus


29-Oct
0.25
0.2
0.15
0.1
0.05
0
2 3 4 5 6 7 8 9 10 11 12 13 14 15 17 18 20
Chironomus
Tanypus


3-Nov
0.25
0.2
0.15
0.1
0.05
0
2 3 4 5 6 7 8 9 10 11 12 13 14 15 17 18 20
Chironomus
Tanypus

Appendix 12. NDSD Sheetflow Wetlands Botanical Survey

The following appendix is a summary of a one-day botanical survey of vascular plants in and around Unit 3, NDSD sheetflow wetlands. Survey was supervised by Blake Wellard, an expert Utah wetlands botanist. Survey was conducted September 11, 2020.

Table 9. List of vascular plant species encountered during a one-day botanical survey conducted in and around Unit 3 of the NDSD sheetflow wetlands.

Asteraceae	Bidens cernua	Nodding beggarticks	Native
Chenopodiaceae	Salicornia rubra	Red swampfire	Native
Chenopodiaceae	Kochia hyssopifolia	Bassia	Non-native
Cyperaceae	Bolboschoenus maritimus	Alkali bulrush	Native
Cyperaceae	Schoenoplectus americanus	Threesquare	Native
Lemnaceae	Lemna gibba	Humped duckweed	Native
Lemnaceae	Lemna minor	Lesser duckweed	Native
Plantaginaceae	Veronica anagallis-aquatica	Water speedwell	Non-native
Poaceace	Polypogon monspeliensis	Rabbitfoot grass	Non-native
Poaceae	Distichilis spicata	Salt grass	Native
Poaceae	Phragmites australis	Common Reed	Non-native
Poaceae	Puccinellia nuttalliana	Nuttalls alkaligrass	Native
Poaceae	Hordeum jubatum	Foxtail barley	Native
Potamogetonaceae	Zannichellia palustris	Horned pondweed	Native
Potamogetonaceae	Potamogeton crispus	Crisped pondweed	Non-native
Potamogetonaceae	Stukenia pectinata	Fennel-leaf pondweed	Native
Ranunculaceae	Ranunculus cymbalaria	Marsh buttercup	Native
Typhaceae	Typha domingensis	Common Cattail	Native

Asteraceae
Bidens cernua,
Nodding beggarticks
Native

- Nodding beggarticks is a robust annual plant that was frequently encountered in shallow open water and exposed mud. Often growing with Veronica anagallis-aquatica cattail and other emergent vegetation.
- Leaves are opposite with serrated margins. Upper leaves are attached directly to the stem.
- The seeds are eaten by waterfowl. The seeds also have barbed awns which allow easy transport by animals (see top left photo).

Chenopodiaceae -
Salicornia rubra
Red swampfire
Native

- Frequency: Common in the saline playa sections of the wetland.
- Annual herb has fleshy stems and scale like leaves with opposite branches. Plants turn red in Autumn.
- Plants accumulate salt and have been investigated for salt remediation in soils.

Photos Sherel Goodrich USFS

Chenopodiaceae
Kochia scoparia
Bassia
Non-native

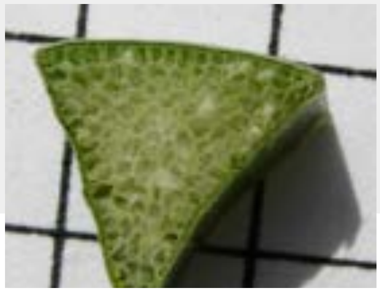
- Frequency: Sporadic throughout drier areas of the wetland.
- Erect annual herbs with alternate often hairy leaves.
- Plants were originally introduced for livestock forage and have escaped and become widespread.

Photos Sherel Goodrich USFS. Additional information USDA plant fact sheet.

Cyperaceae
Bolboschoenus maritimus
Alkali bulrush
Native

- Frequency: *Bolboschoenus maritimus* was frequently observed and sometimes abundant in places like the salt-grass marsh. In the emergent marsh, plants were generally occupying the margins of cattail or phragmites stands.
- The plants typically have 1 -3 long leaf like bracts in their inflorescence. The flowers are attached directly to the stem. The stems are three sided but not deeply concave like *Schoenoplectus americanus.*
- The seeds and tubers are a food source for wildlife.

Photos Blake Wellard and Sherel Goodrich. Additional Information: Wetland Plants of Colorado.



Cyperaceae
Schoenoplectus americanus
Threesquare
Native

- Frequency: Uncommon. Only observed in sections of the marsh where phragmites and cattail densities were lower. Common statewide.
- The strongly triangular, deeply concave three-sided stem are diagnostic for this species.
- Rhizomes and seeds are important food source for wildlife.

Lemnaceae
Lemna gibba
Humped duckweed
Native

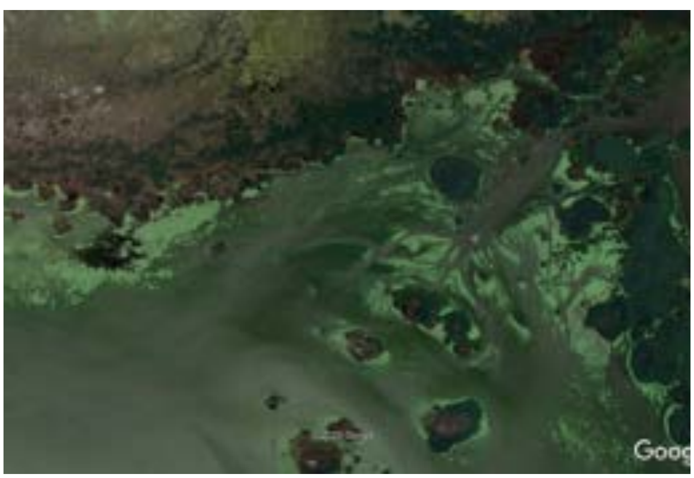
- Frequency: This is the most common floating aquatic observed at Farmington Bay Wetlands. Lemna minor is present to but much less abundant at the date of the survey.
- *Lemna gibba* is easily identified by the swollen/inflated (gibbous) underside of the leaf. *Lemna minor* is not swollen or inflated.
- Highly nutritious food source for fish, birds and other wildlife.

Lemnaceae- *Lemna minor*
Lesser duckweed
Native

- Frequency: Only occasional seen mixed in with *Lemna gibba*.
- This duckweed species lacks the inflated underside. Commonly reproduces vegetatively.
- Highly nutritious food source for fish, birds and other wildlife.

Photo Credit: Sherel Goodrich USFS. Wikipedia. Additional information: Wetland Plants of Colorado

Lemnaceae
Lemna gibba
Humped duckweed Native



- All of the light/lime green sections in this aerial image are *Lemna minor* and *Lemna gibba.* Both of these plants are providing a major ecological role in this wetland.

Plantaginaceae
Veronica anagallis-aquatica
Water speedwell
Non-native

- Frequency: Only observed with *Bidens cernua* in shallow open water sections of the wetland.
- Plants have stems that are up to 1m tall that emerge out of the water when in flower. Plants have opposite leaves and the leaves on the stem are sessile and clasping the stem.
- This plant is widespread and can be seen in shallow water and slow-moving water throughout the state.

Poaceace
Polypogon monspeliensis
Rabbitfoot grass
Non-native

- Frequency: Rabbitfoot grass was found mixed in with the salt grass outside of the emergent marsh areas.
- Rabbitfoot grass is an easy to recognize annual species when in flower. The thick/wide inflorescence is covered with soft awns that simulate the appearance of fur.



Poaceae
Distichilis spicata
Salt grass
Native

- Frequency: Abundant in the shallow marsh sections of the wetland. Salt grass can form extensive stands and sometimes forms monocultures. In Farmington Bay marsh sections, Salt grass was most frequently co-dominant with *Bolboschoenus maritimus.*
- Salt grass reproduces extensively from rhizomes. Stems are covered with short alternate leaves.
- When present in sufficient numbers, this and other grasses provide food, shelter and nesting materials for small animals and birds.



Poaceae
Phragmites australis
Common Reed or phragmites
Non-native

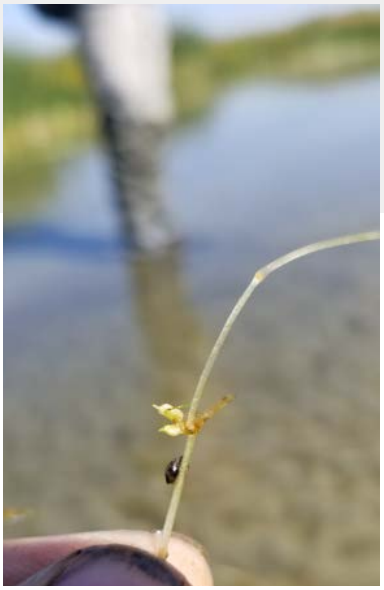
- Frequency: Phragmites alongside cattail were the dominant species of the emergent marsh.
- The robust size, large inflorescene and tendency to form monocultures suggests that all phragmites present at this section of Farmington Bay belong to the Eurasian subspecies.
- Phragmites reproduces through stolon's, rhizomes and seeds and quickly colonize marshlands.
- Phragmites does have wetland remediation benefits by removing nutrients and heavy metals from the system and storing them in their biomass.

Poaceae
Puccinellia nuttalliana
Nuttalls alkaligrass
Native

- Frequency: Only observed in the salt grass marsh sections of the wetland.
- Small perennial bunch grass that readily colonizes drying mudflats and semi-wet meadow areas.
- When present in sufficient numbers, this and other grasses provide food, shelter and nesting materials for small animals and birds.

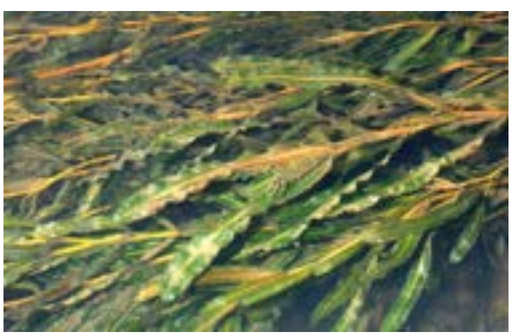
Poaceae *Hordeum jubatum* Foxtail barley Native

- Frequency: Uncommon. Mostly observed with rabbitfoot grass and salt grass in some of the shallow marsh areas that periodically dry out.
- The long-awned drooping inflorescences set this grass apart from any other at the Farmington Bay site.
- This perennial species readily colonizes new exposed ground especially in places with abundant soil moisture.



Potamogetonaceae
Zannichellia palustris
Horned pondweed
Native

- Frequency: Most commonly encountered submerged aquatic plant observed during Farmington Bay vegetation survey. Sometimes found growing intermixed with *Stukenia filiformis and Potamogeton crispus*.
- Leaves are opposite opposed to alternate of the latter two species mentioned above. Flowers/achenes are in the axils of the leaves.
- Tolerant of brackish water, human disturbance and eutrophication.
- Provides food for waterfowl and small fish. Shelter for macroinvertebrates.

Potamogetonaceae
Potamogeton crispus
Crisped pondweed
Non-native

- Frequency: Crisped pondweed is not common in the wetland sections explored.
- The curly and serrated leave margin are diagnostic for this submergent aquatic.
- This non-native submergent provides for and cover for animals and homes for macroinvertebrates.


Potamogetonaceae
Stukenia pectinata
Fennel-leaf pondweed
Native

- Frequency: Second most common submergent aquatic observed. Often observed with *Zanichellia palustris* in the main channel of the wetland.
- Plants with alternate leaves and achenes arising from a long peduncle that is generally well separated from the leaves.
- Provides food for wildlife and cover for small vertebrates and macroinvertebrates.


Ranunculaceae
Ranunculus cymbalaria
Marsh buttercup
Native

- Frequency: Uncommon. Only observed on one muddy shoreline.
- Plants are amphibious so they are capable of occupying terrestrial, marginal and emergent positions within the wetland. Plants produce numerous achenes and often reproduce vegetatively through stolons.

Typhaceae
Typha latifolia
Common Cattail
Native

- Frequency: Abundant in the shallow to deeper water sections of the wetland. Sometimes co-dominant with Phragmites.
- Common cattail lacks separation from the male (upper flowers)and female flowers (lower flowers). *Typha domingensis* is likely also present. The male and female flowers of that species are separated.
- Common cattail is an important food source for waterfowl and small and large mammals.
- Cattail can abord large amounts of nutrients from the system during periods of rapid growth.

Zhao, Y., Yang, Z., Xia, X., & Wang, F. (2012). A shallow lake remediation regime with Phragmites australis: incorporating nutrient removal and water evapotranspiration. water research, 46(17), 5635-5644.ake Wellard and Sherel Goodrich USFS

Meuleman, Arthur FM, J. Hans Ph Beekman, and Jos TA Verhoeven. "Nutrient retention and nutrient-use efficiency in Phragmites australis stands after wasterwater application." Wetlands 22.4 (2002): 712-721.

Appendix 13. Fractional probit regression of precent vegetation as a function of sample site location. Data collected on September 2, 2020

Stata code: fracreg probit PercentVeg i.sitecode, vce(robust)

```
Fractional probit regression                    Number of obs     =         80
                                                Wald chi2(3)      =     227.94
                                                Prob > chi2       =     0.0000
Log pseudolikelihood = -13.895803               Pseudo R2         =     0.6732

------------------------------------------------------------------------------
             |               Robust
  PercentVeg |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    sitecode |
         4B  |     -0.463      0.079   -5.858   0.000       -0.618      -0.308
         4C  |     -0.481      0.077   -6.249   0.000       -0.632      -0.330
         5A  |      2.846      0.255   11.174   0.000        2.347       3.345
             |
       _cons |     -1.845      0.077  -23.967   0.000       -1.996      -1.694
------------------------------------------------------------------------------
```

Appendix 14. Negative binomial regression results of plant height as a function of site location and type of vegetation. Data collected on October 1, 2020

```
Stata code: nbreg SAVheightCM i.SiteCode##i.vegcode, dispersion(mean) irr

Negative binomial regression                    Number of obs     =        148
                                                LR chi2(10)       =     351.72
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -311.15286                     Pseudo R2         =     0.3611

----------------------------------------------------------------------------------
     SAVheightCM |        IRR   Std. Err.      z    P>|z|     [95% Conf. Interval]
-----------------+----------------------------------------------------------------
        SiteCode |
              4  |      3.289      1.255    3.120   0.002        1.557       6.950
              5  |      2.400      1.013    2.074   0.038        1.050       5.490
                 |
         vegcode |
  Benthic Algae  |      0.489      0.186   -1.876   0.061        0.232       1.033
        Bulrush  |     39.254      7.074   20.367   0.000       27.574      55.882
       Pondweed  |      4.386      1.991    3.257   0.001        1.802      10.678
                 |
SiteCode#vegcode |
4#Benthic Algae  |      0.516      0.276   -1.237   0.216        0.181       1.472
      4#Bulrush  |      0.229      0.091   -3.724   0.000        0.105       0.497
     4#Pondweed  |      0.442      0.257   -1.402   0.161        0.141       1.384
   5#Cladophora  |      1.000  (empty)
5#Benthic Algae  |      0.436      0.383   -0.945   0.345        0.078       2.442
      5#Bulrush  |      0.209      0.100   -3.275   0.001        0.082       0.534
     5#Pondweed  |      1.000  (omitted)
                 |
           _cons |      1.368      0.235    1.820   0.069        0.976       1.917
-----------------+----------------------------------------------------------------
        /lnalpha |     -4.628      0.939                        -6.468      -2.787
-----------------+----------------------------------------------------------------
           alpha |      0.010      0.009                         0.002       0.062
----------------------------------------------------------------------------------
```

Appendix 15. Photographs of vegetation cover within 1 m^{-2} quadrats.

Site 5A

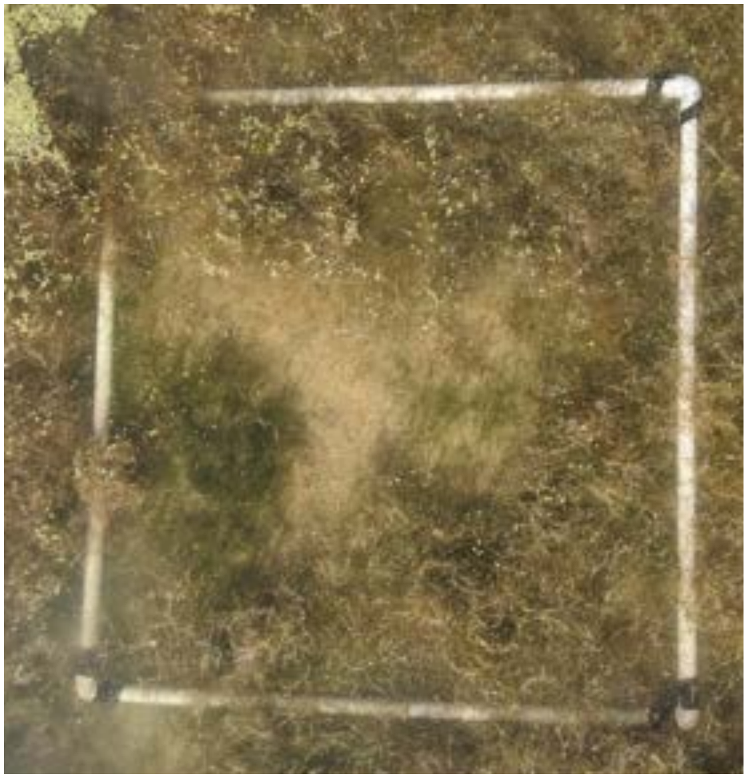


Figure 5A- (1/20) Vegetation Estimation. 75% Vegetation coverage.

Figure 5A- (2/20) Vegetation Estimation. 99% Vegetation coverage.

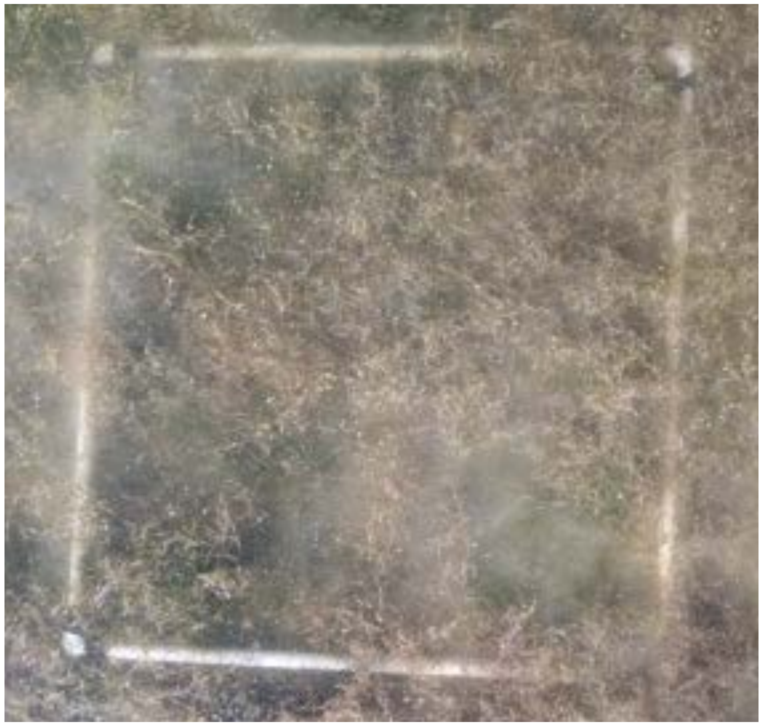


Figure 5A- (3/20) Vegetation Estimation. 99% Vegetation coverage.

Figure 5A- (4/20) Vegetation Estimation. 99% Vegetation coverage.

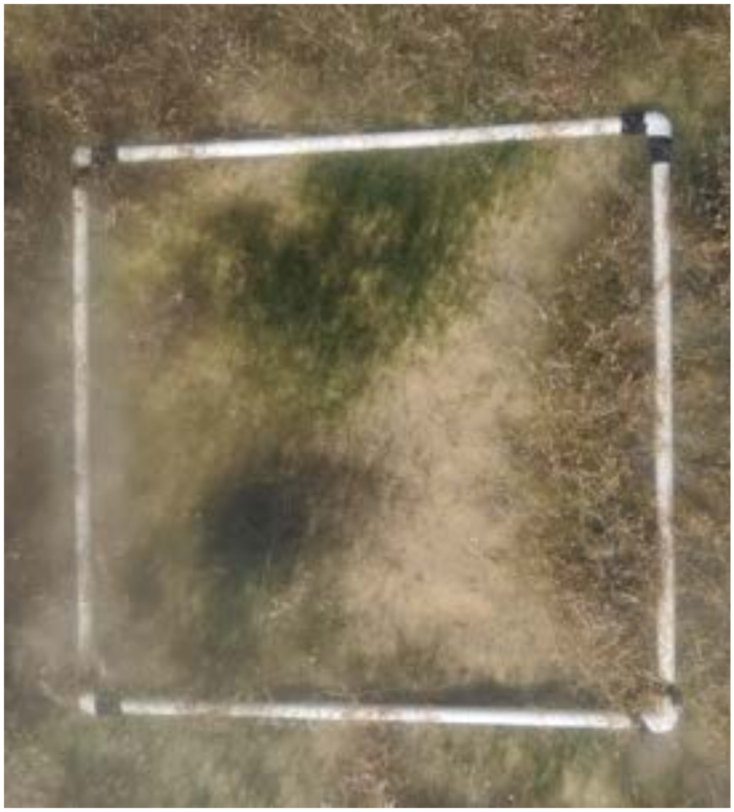


Figure 5A- (5/20) Vegetation Estimation. 50% Vegetation coverage.

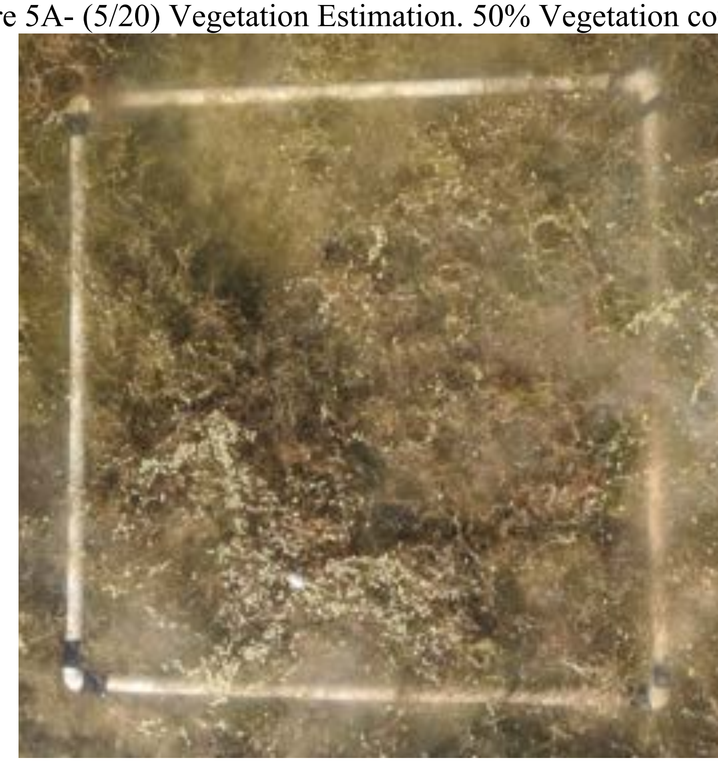


Figure 5A- (6/20) Vegetation Estimation. 90% Vegetation coverage.

Figure 5A- (7/20) Vegetation Estimation. 90% Vegetation coverage.

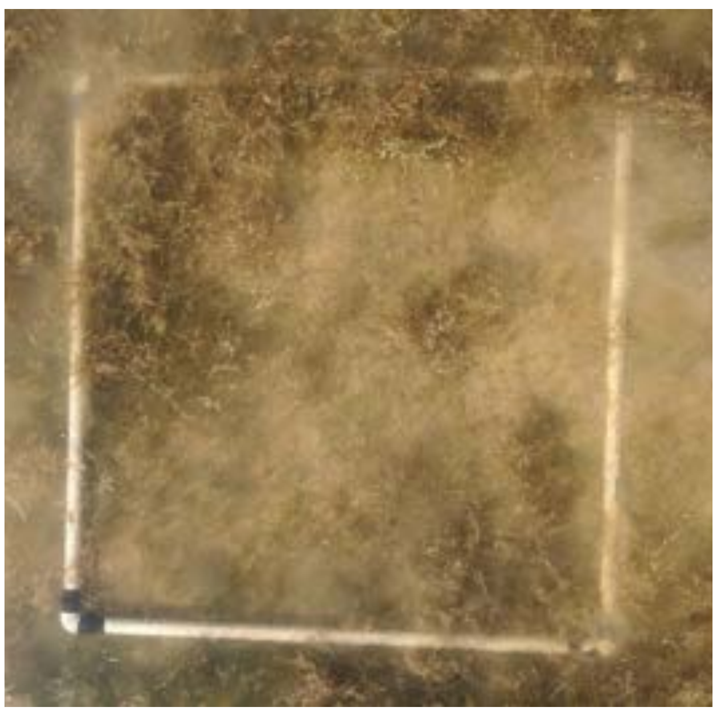


Figure 5A- (8/20) Vegetation Estimation. 80% Vegetation coverage.

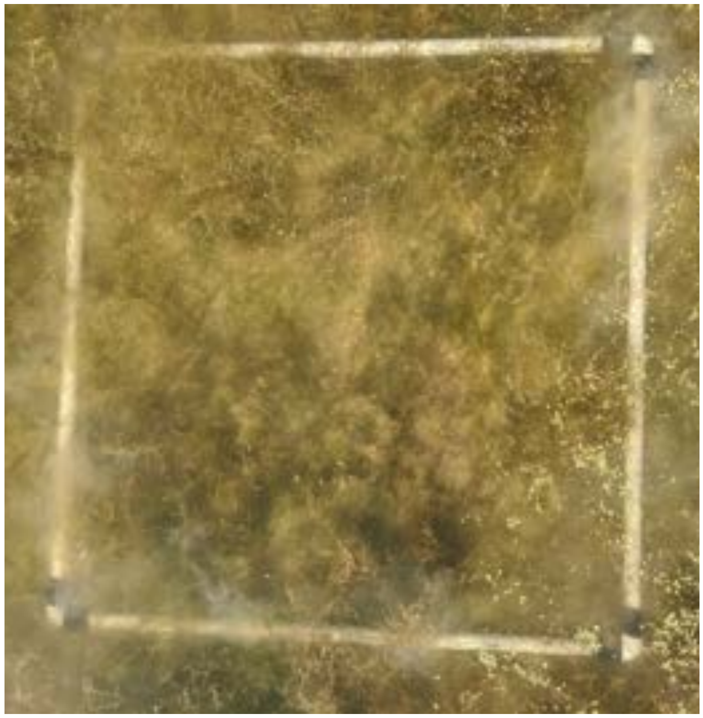


Figure 5A- (9/20) Vegetation Estimation. 99% Vegetation coverage.

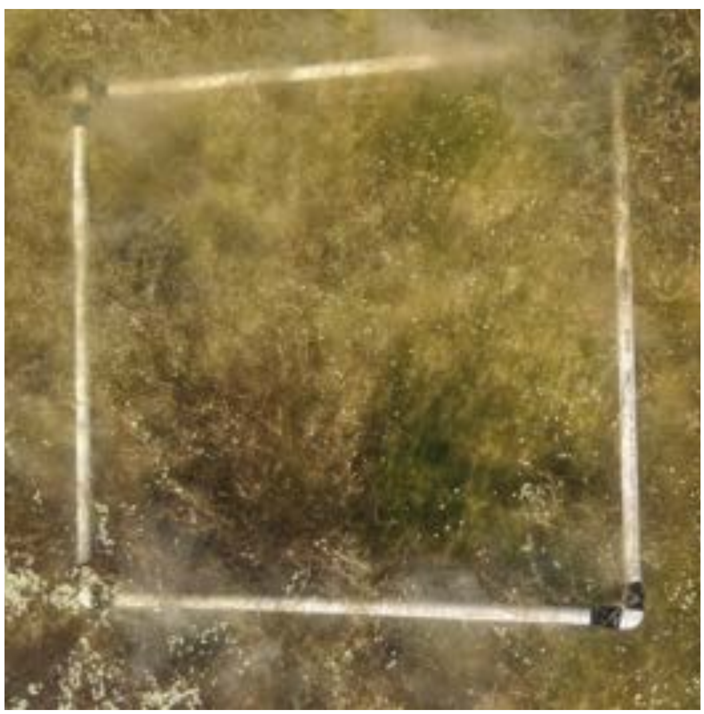


Figure 5A- (10/20) Vegetation Estimation. 99% Vegetation coverage.

Figure 5A- (11/20) Vegetation Estimation. 99% Vegetation coverage.

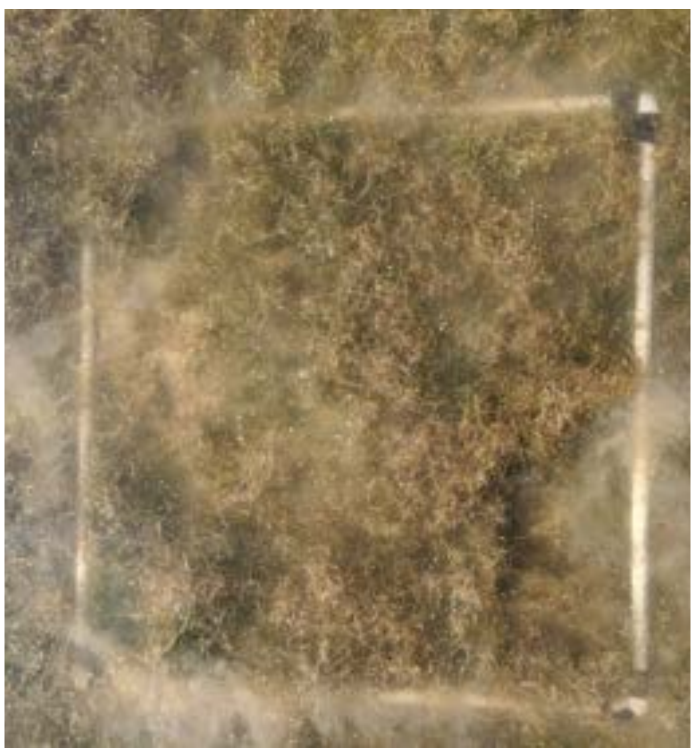


Figure 5A- (12/20) Vegetation Estimation. 99% Vegetation coverage.

Figure 5A- (13/20) Vegetation Estimation. 80% Vegetation coverage.

Figure 5A- (14/20) Vegetation Estimation. 99% Vegetation coverage.

Figure 5A- (15/20) Vegetation Estimation. 10% Vegetation coverage.

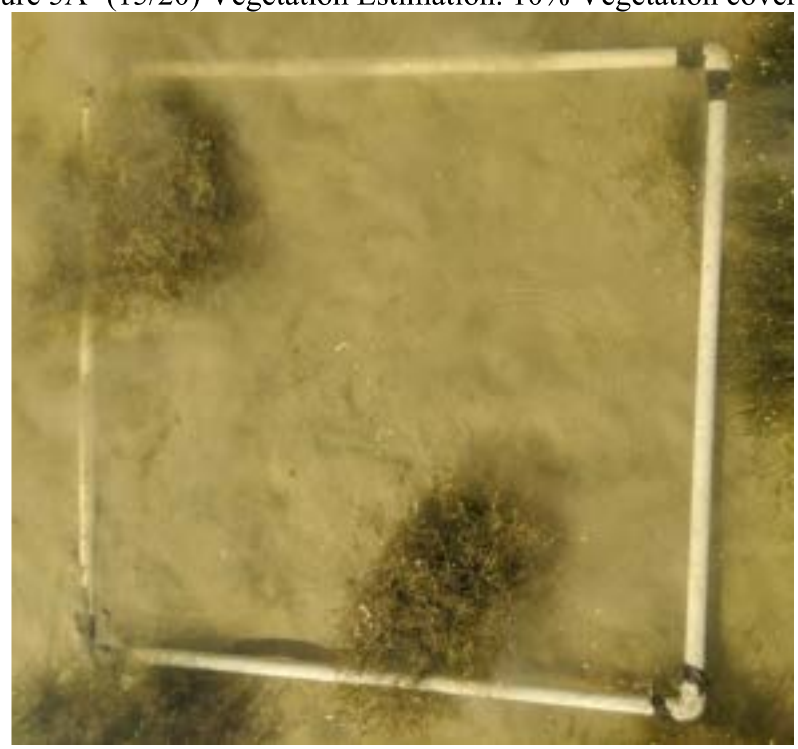


Figure 5A- (16/20) Vegetation Estimation. 20% Vegetation coverage

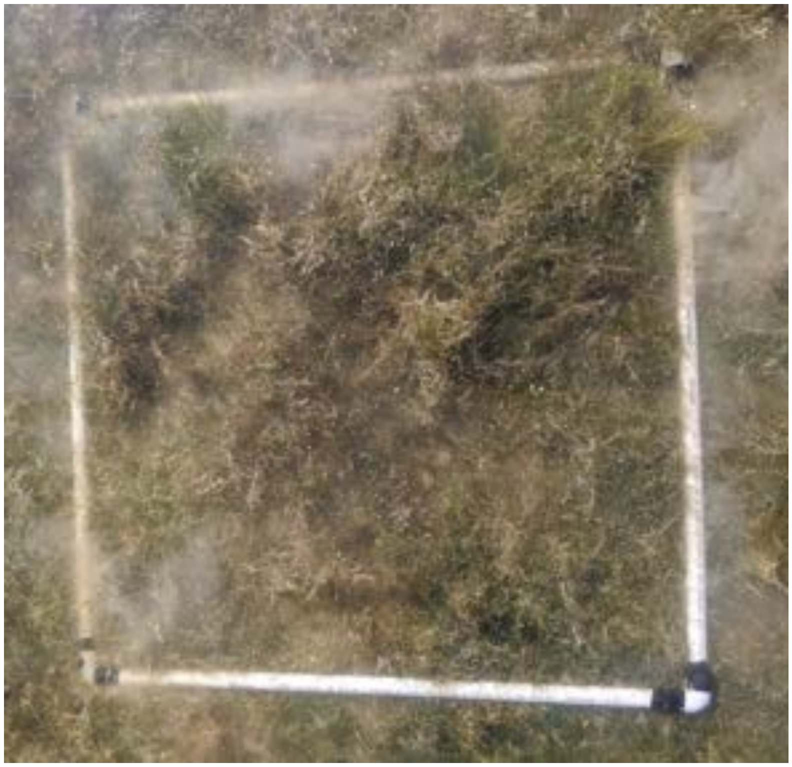


Figure 5A- (17/20) Vegetation Estimation. 99% Vegetation coverage.

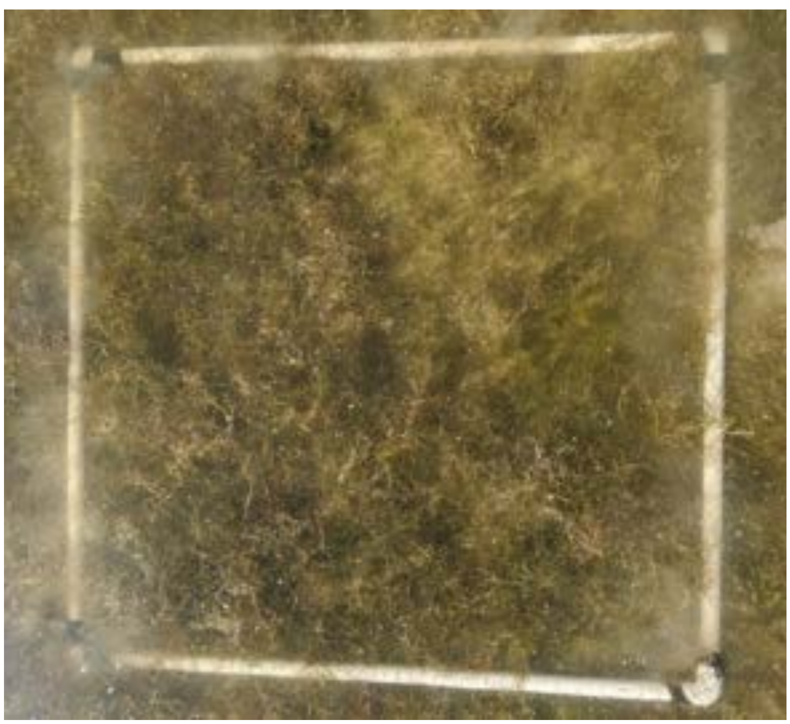


Figure 5A- (18/20) Vegetation Estimation. 99% Vegetation coverage.

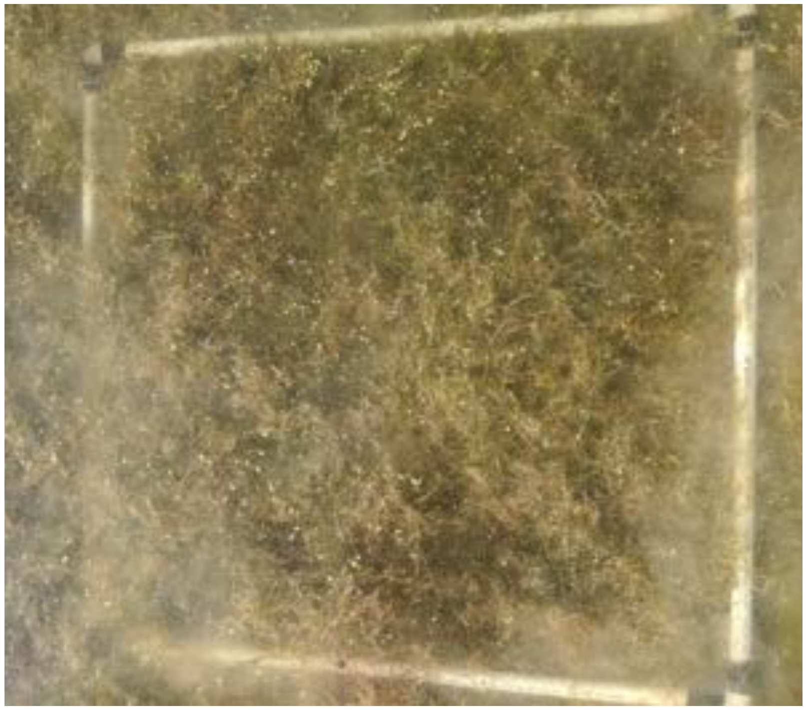


Figure 5A- (19/20) Vegetation Estimation. 99% Vegetation coverage.

Figure 5A- (20/20) Vegetation Estimation. 99% Vegetation coverage.
Site 4C

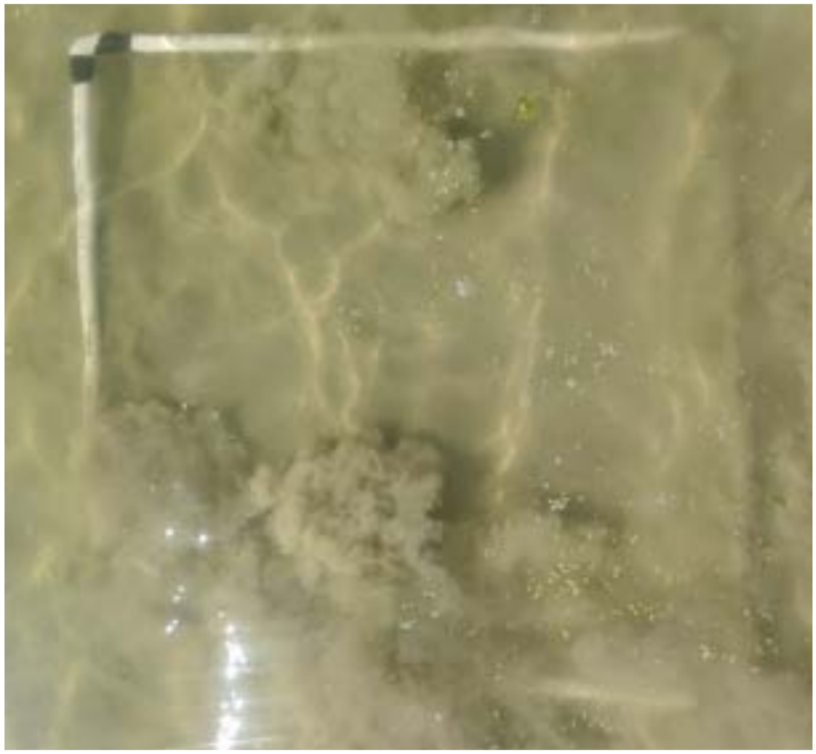


Figure 4C-(1/20) Vegetation Estimation. 1 % Vegetation coverage.

Figure 4C-(2/20) Vegetation Estimation. 1 % Vegetation coverage.

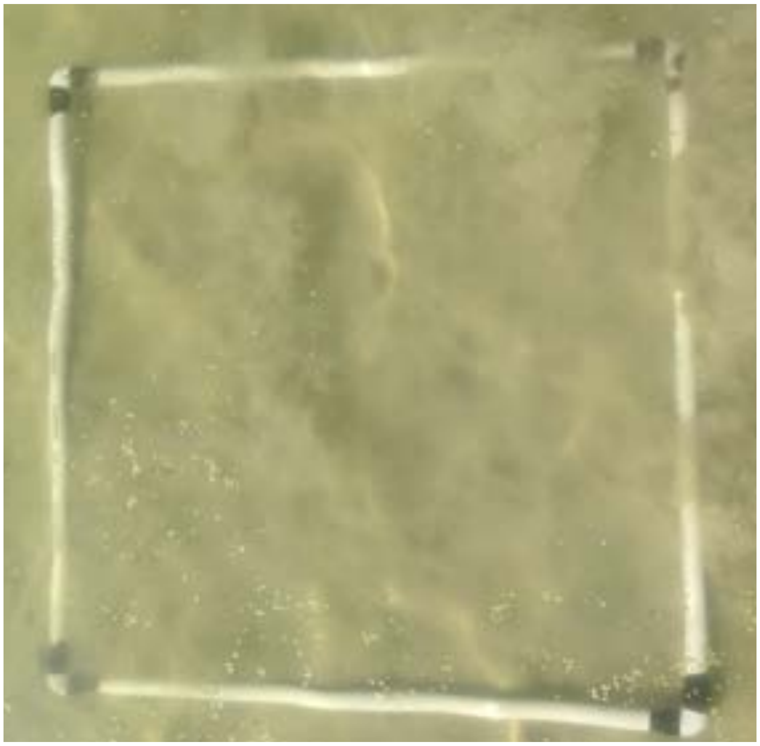


Figure 4C-(3/20) Vegetation Estimation. 1 % Vegetation coverage.

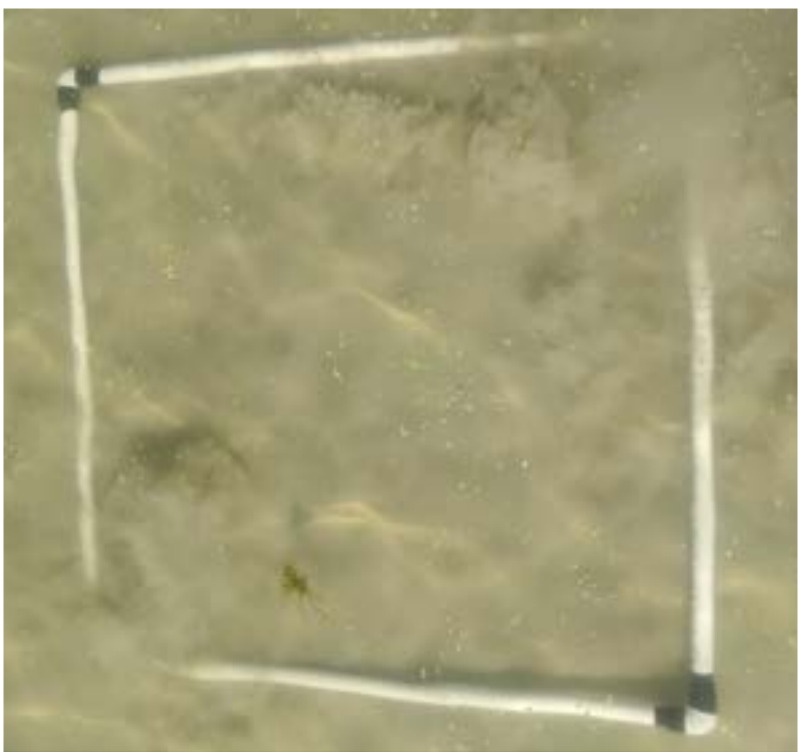


Figure 4C-(4/20) Vegetation Estimation. 1 % Vegetation coverage.

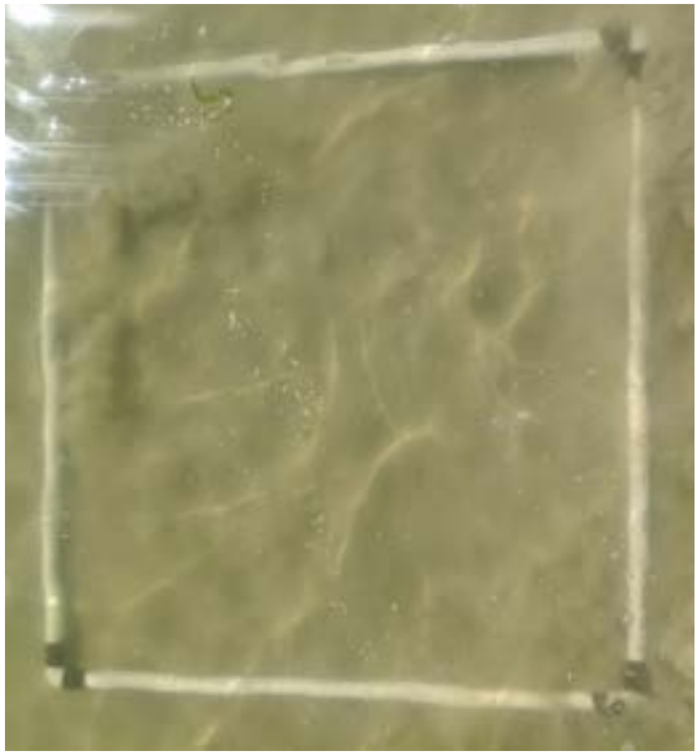


Figure 4C-(5/20) Vegetation Estimation. 1 % Vegetation coverage.

Figure 4C-(6/20) Vegetation Estimation. 1 % Vegetation coverage.

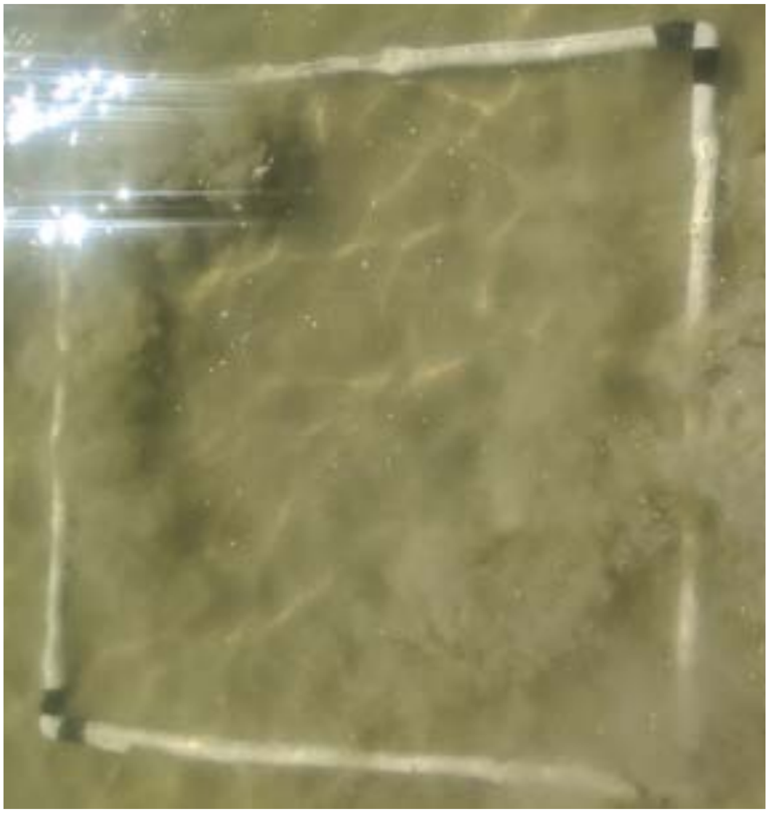


Figure 4C-(7/20) Vegetation Estimation. 1 % Vegetation coverage.

Figure 4C-(8/20) Vegetation Estimation. 1 % Vegetation coverage.

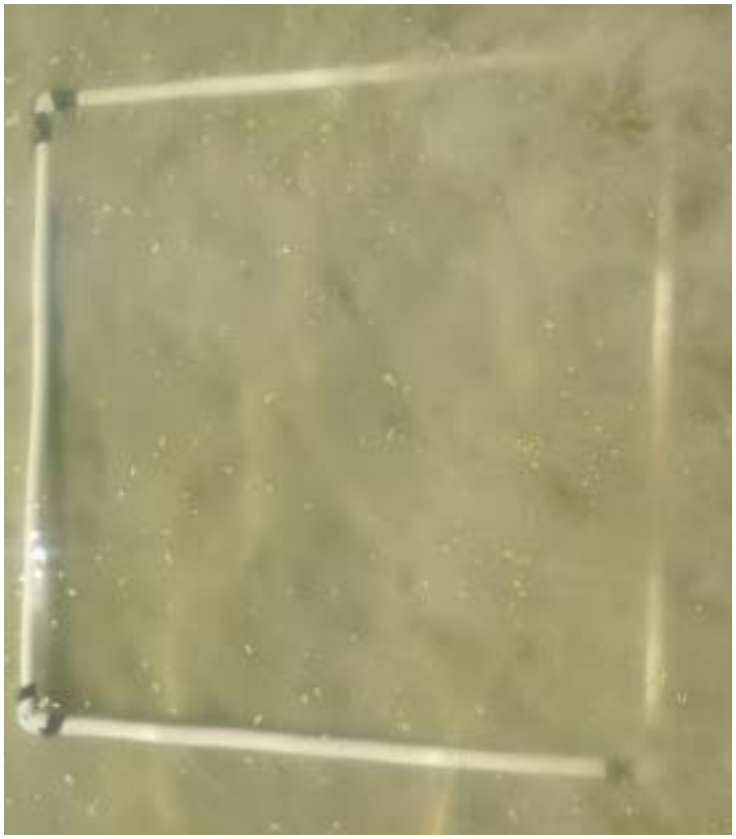


Figure 4C-(9/20) Vegetation Estimation. 1 % Vegetation coverage.

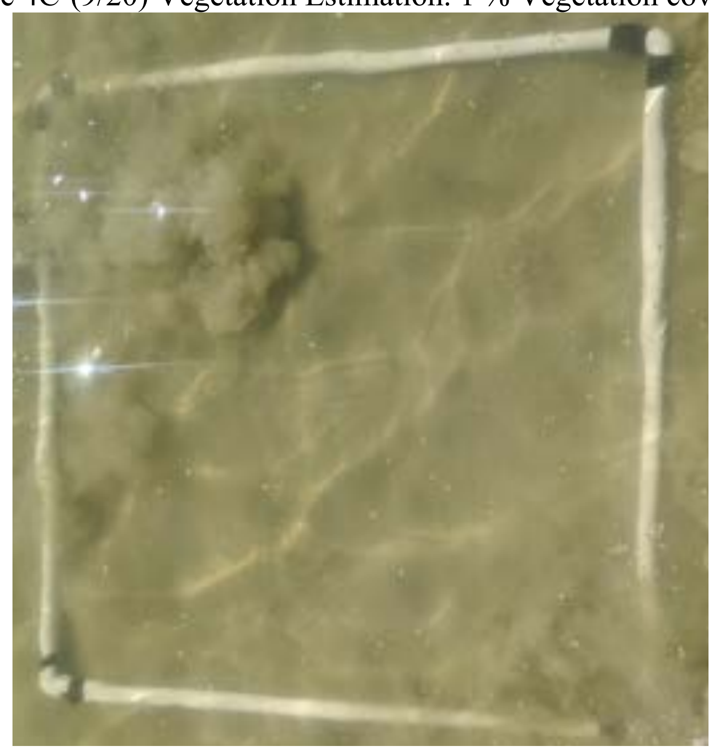


Figure 4C-(10/20) Vegetation Estimation. 1 % Vegetation coverage.

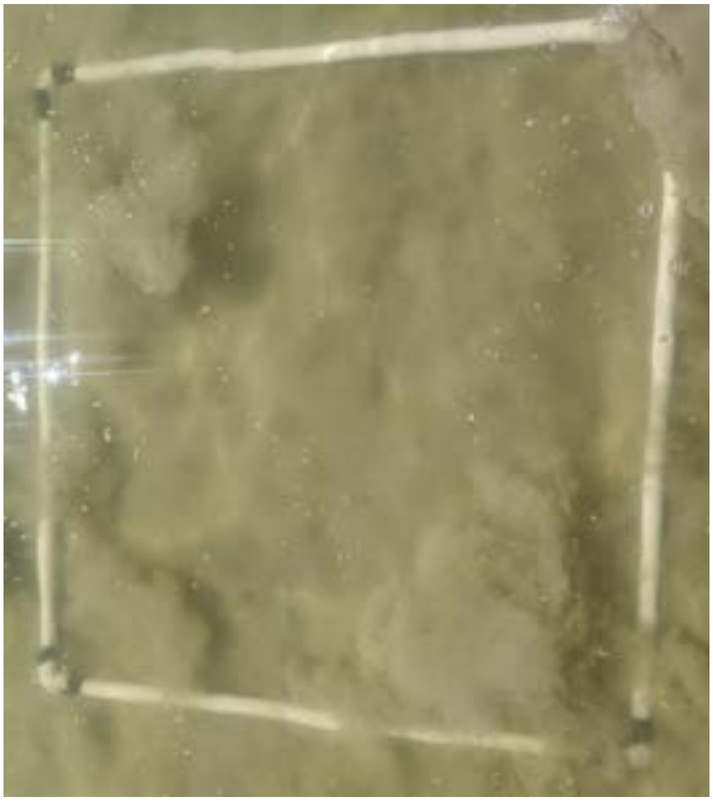


Figure 4C-(11/20) Vegetation Estimation. 1 % Vegetation coverage.

Figure 4C-(12/20) Vegetation Estimation. 1 % Vegetation coverage.

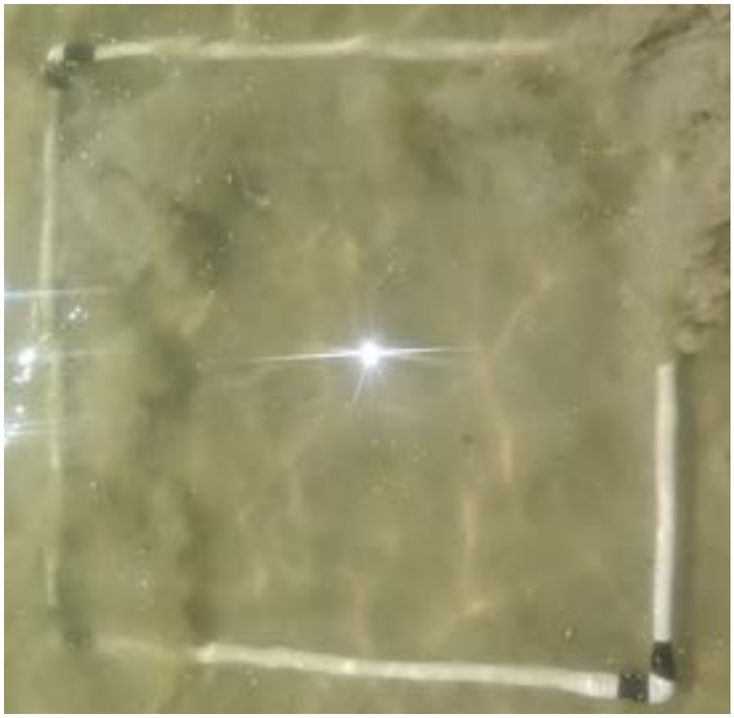


Figure 4C-(13/20) Vegetation Estimation. 1 % Vegetation coverage.

Figure 4C-(14/20) Vegetation Estimation. 1 % Vegetation coverage.

Figure 4C-(15/20) Vegetation Estimation. 1 % Vegetation coverage.

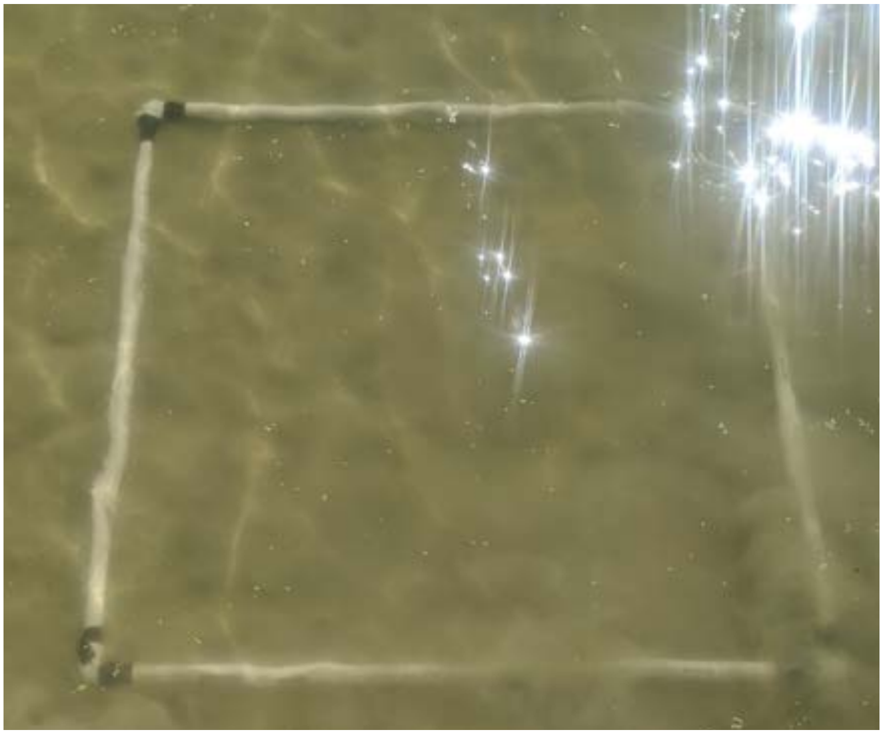


Figure 4C-(16/20) Vegetation Estimation. 1 % Vegetation coverage.

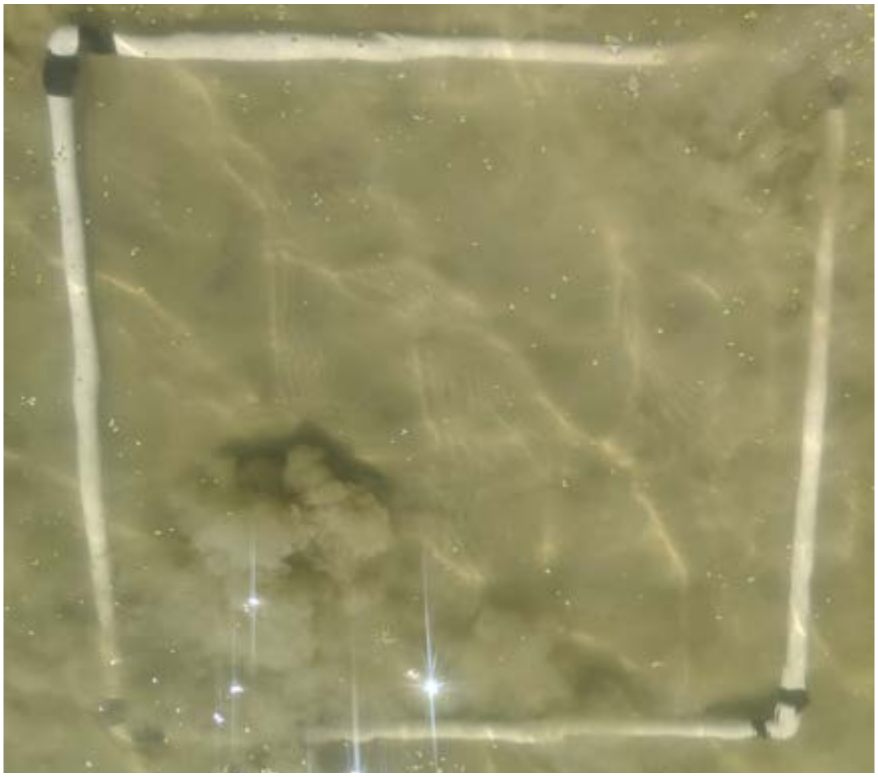


Figure 4C-(17/20) Vegetation Estimation. 1 % Vegetation coverage.

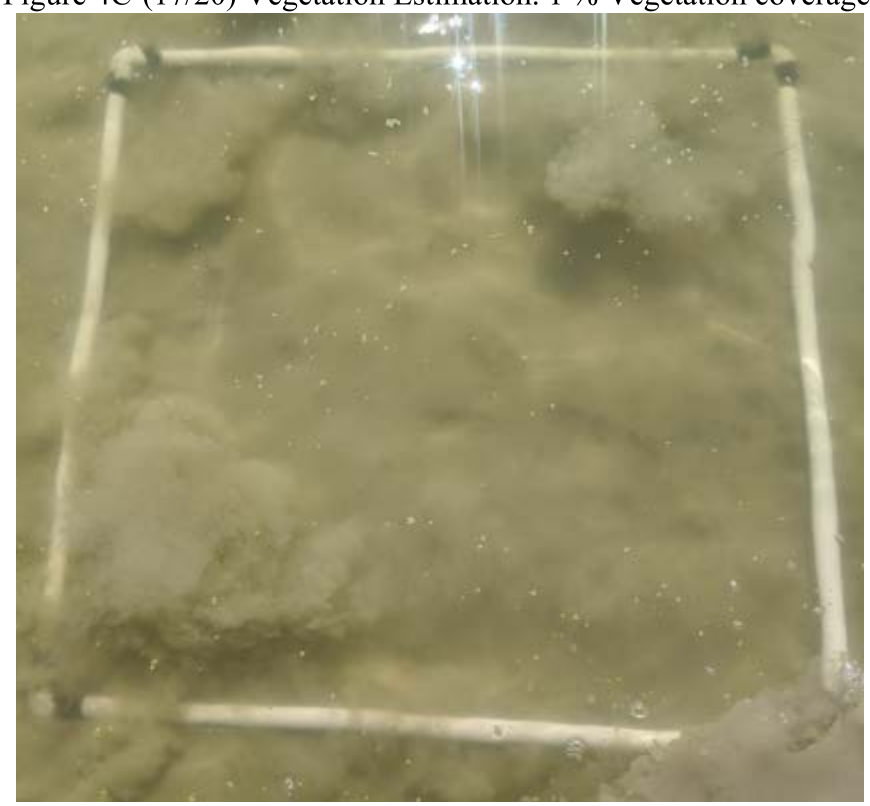


Figure 4C-(18/20) Vegetation Estimation. 1 % Vegetation coverage.

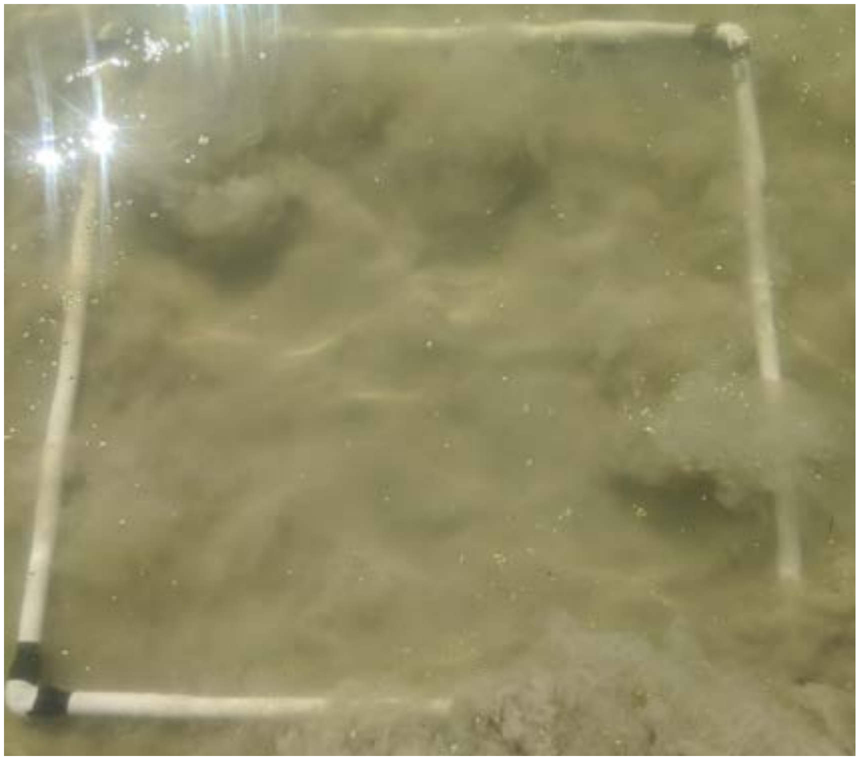


Figure 4C-(19/20) Vegetation Estimation. 1 % Vegetation coverage.

Figure 4C-(20/20) Vegetation Estimation. 1 % Vegetation coverage.

Site 4B


Figure 4B-(1/20) Vegetation Estimation. 1 % Vegetation coverage.


Figure 4B-(2/20) Vegetation Estimation. 1 % Vegetation coverage.

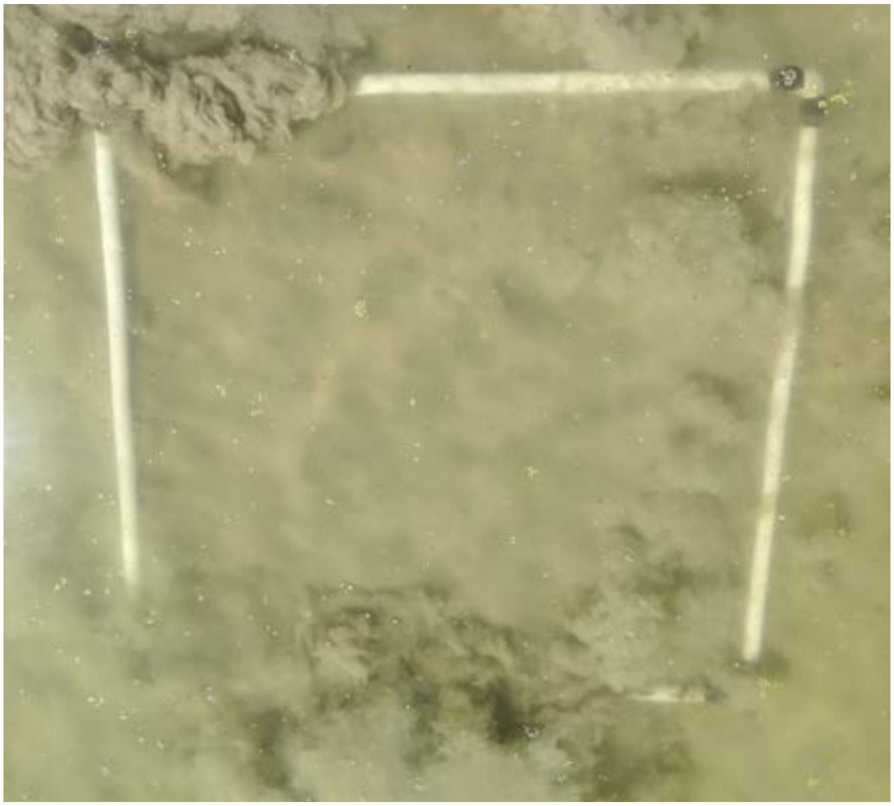


Figure 4B-(3/20) Vegetation Estimation. 1 % Vegetation coverage.

Figure 4B-(4/20) Vegetation Estimation. 1 % Vegetation coverage.

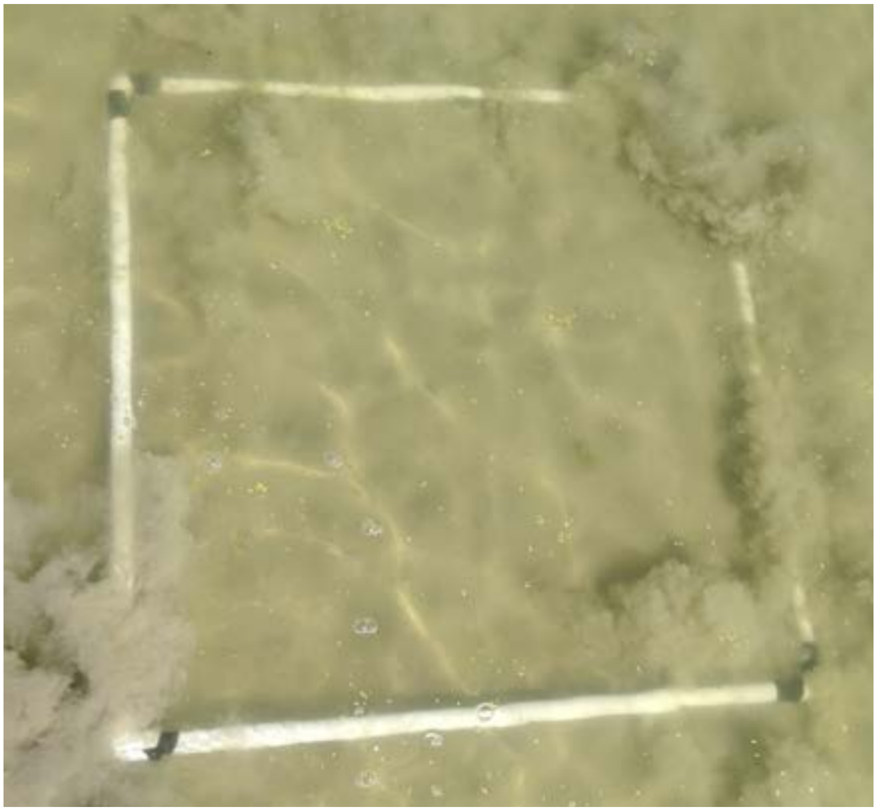


Figure 4B-(5/20) Vegetation Estimation. 1 % Vegetation coverage.


Figure 4B-(6/20) Vegetation Estimation. 1 % Vegetation coverage.

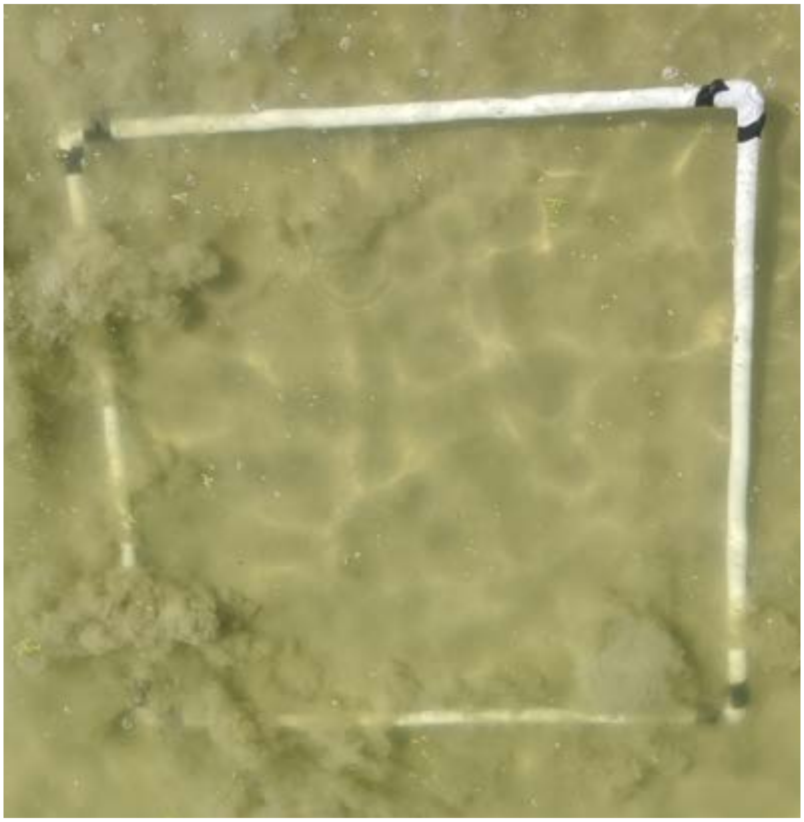


Figure 4B-(7/20) Vegetation Estimation. 1 % Vegetation coverage.

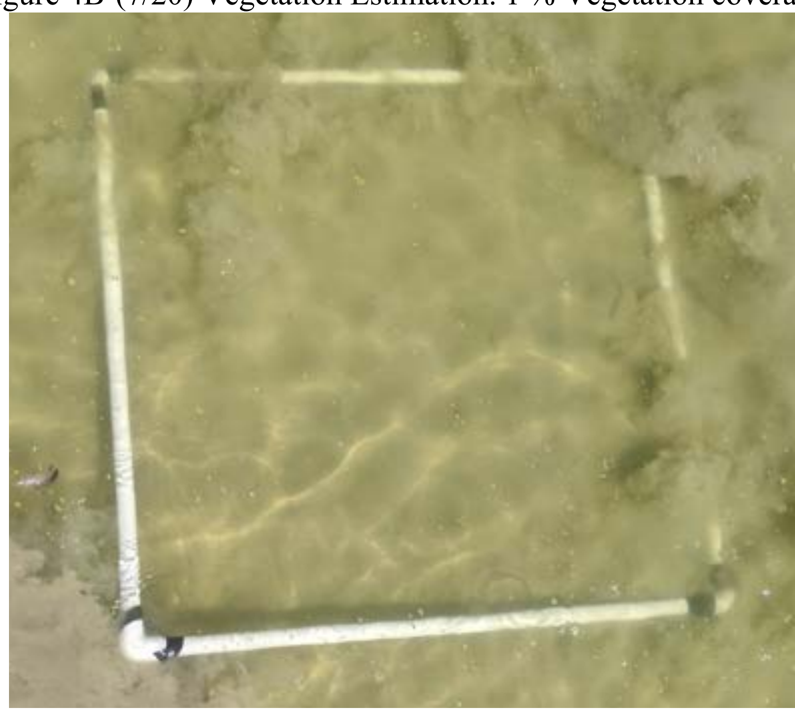


Figure 4B-(8/20) Vegetation Estimation. 1 % Vegetation coverage.

Figure 4B-(9/20) Vegetation Estimation. 1 % Vegetation coverage.

Figure 4B-(10/20) Vegetation Estimation. 1 % Vegetation coverage

Figure 4B-(11/20) Vegetation Estimation. 2 % Vegetation coverage

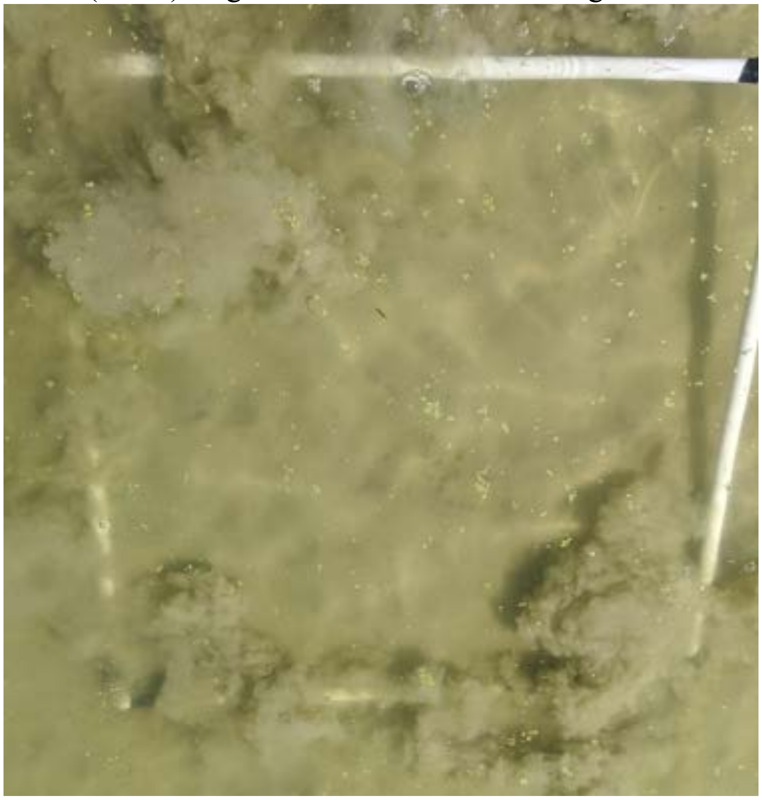


Figure 4B-(12/20) Vegetation Estimation. 1 % Vegetation coverage

Figure 4B-(13/20) Vegetation Estimation. 1 % Vegetation coverage

Figure 4B-(14/20) Vegetation Estimation. 1 % Vegetation coverage

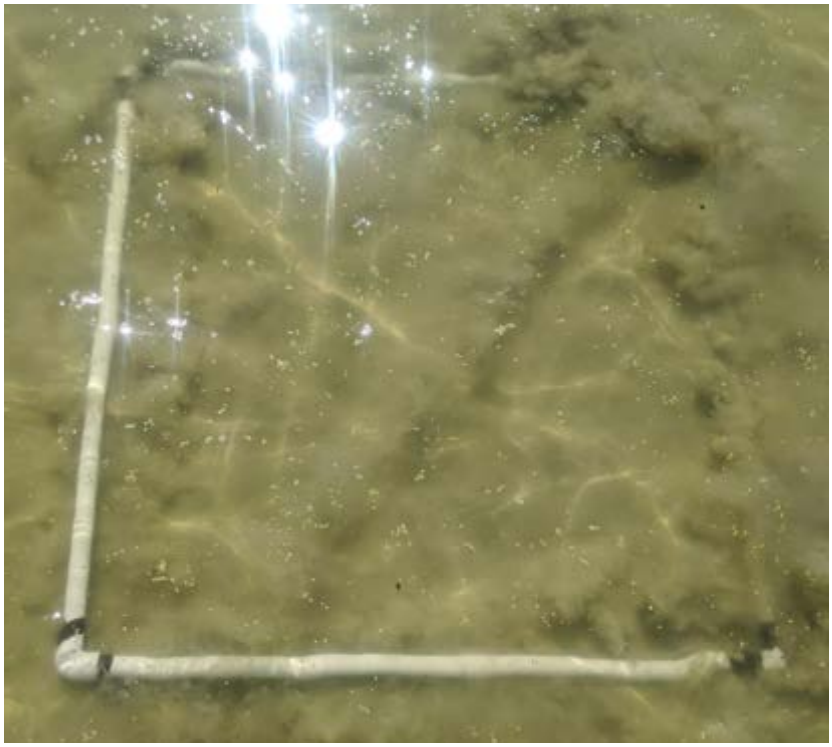


Figure 4B-(15/20) Vegetation Estimation. 1 % Vegetation coverage

Figure 4B-(16/20) Vegetation Estimation. 1 % Vegetation coverage

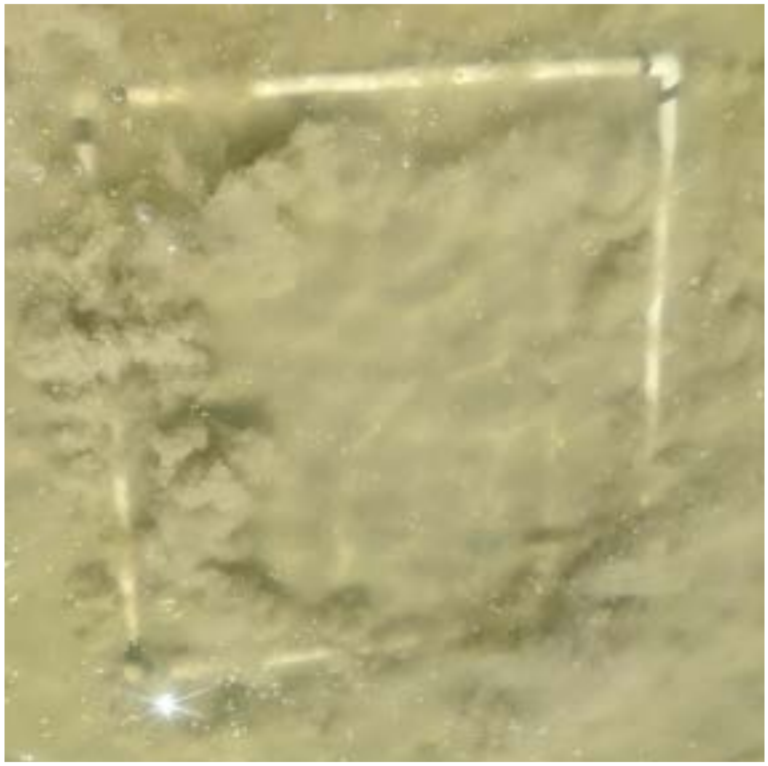


Figure 4B-(17/20) Vegetation Estimation. 1 % Vegetation coverage

Figure 4B-(18/20) Vegetation Estimation. 1 % Vegetation coverage

Figure 4B-(19/20) Vegetation Estimation. 1 % Vegetation coverage

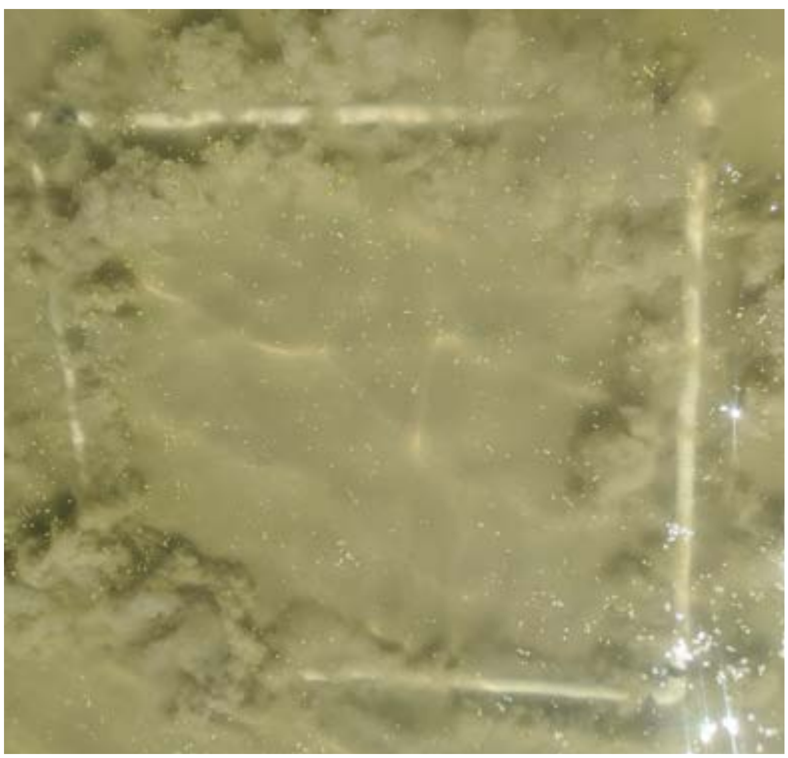


Figure 4B-(20/20) Vegetation Estimation. 1 % Vegetation coverage

Site 4A

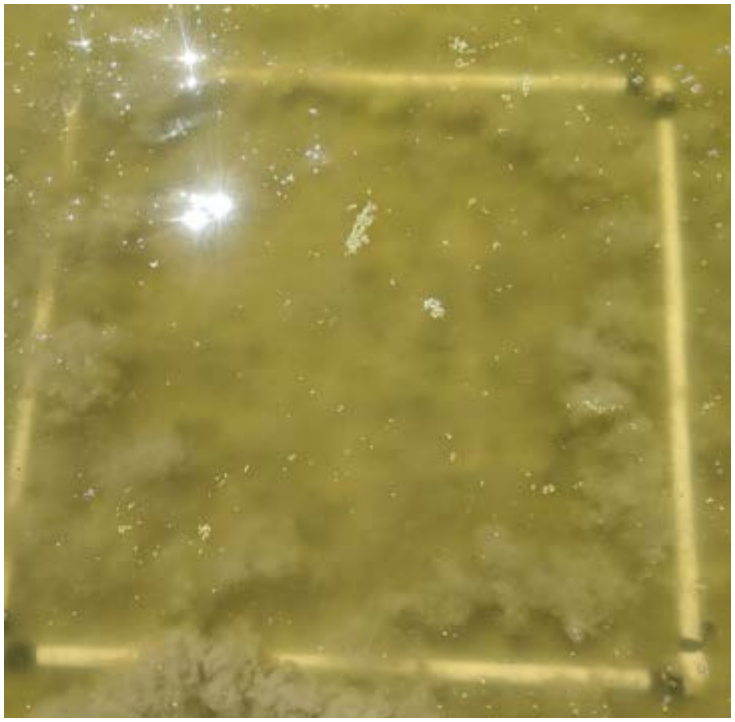


Figure 4A-(1/20) Vegetation Estimation. 1% Vegetation coverage.

Figure 4A-(2/20) Vegetation Estimation. 5% Vegetation coverage

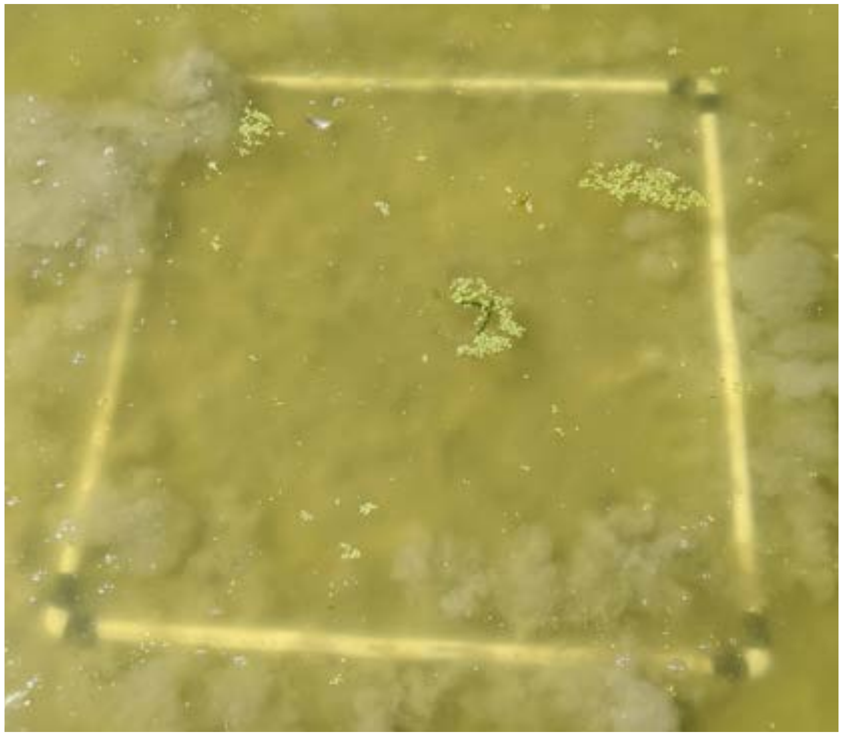


Figure 4A-(3/20) Vegetation Estimation. 5% Vegetation coverage

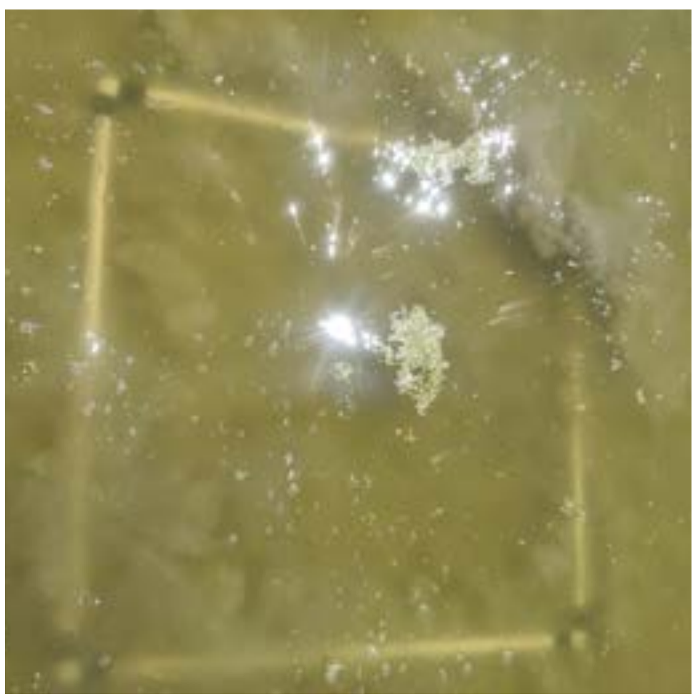


Figure 4A-(4/20) Vegetation Estimation. 5% Vegetation coverage

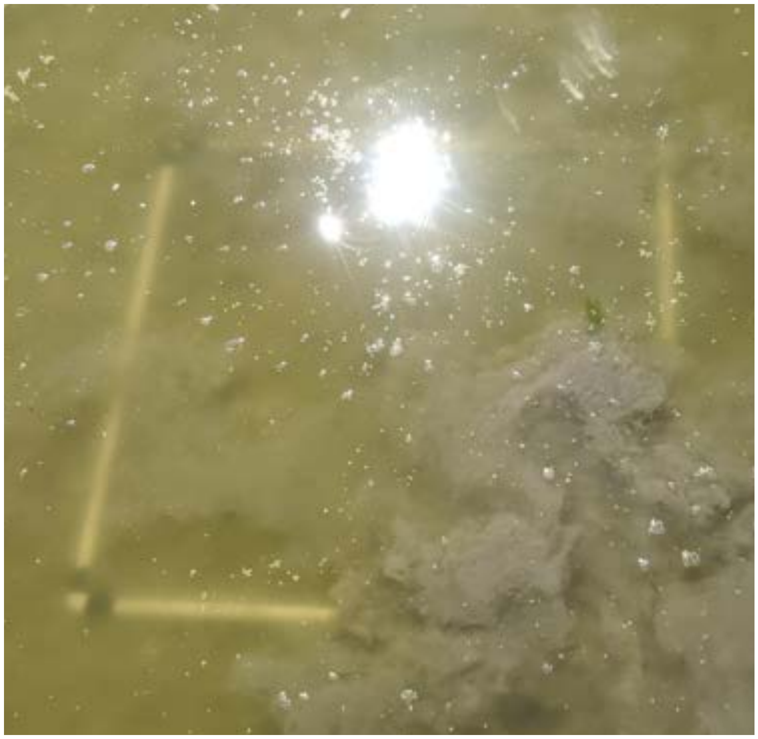


Figure 4A-(5/20) Vegetation Estimation. 1% Vegetation coverage

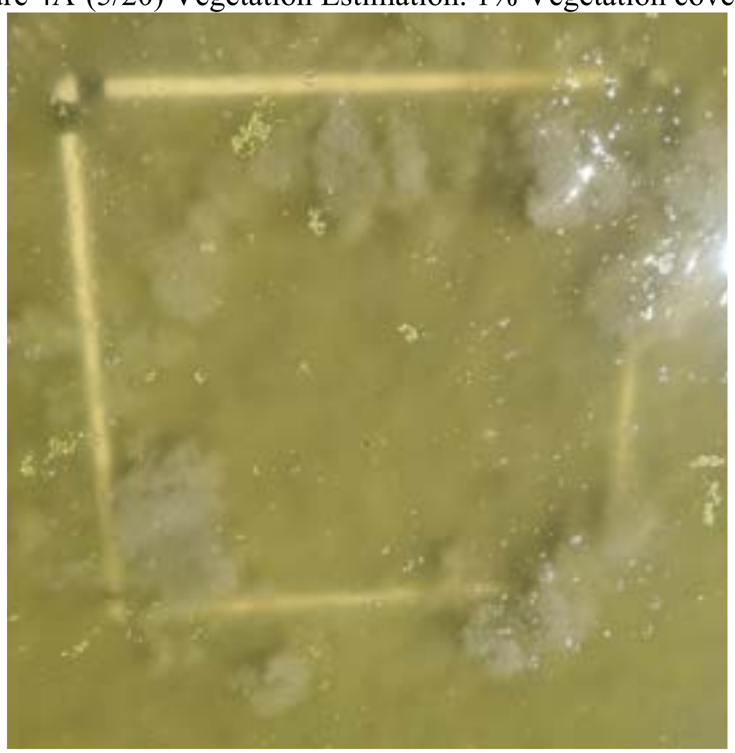


Figure 4A-(6/20) Vegetation Estimation. 1% Vegetation coverage

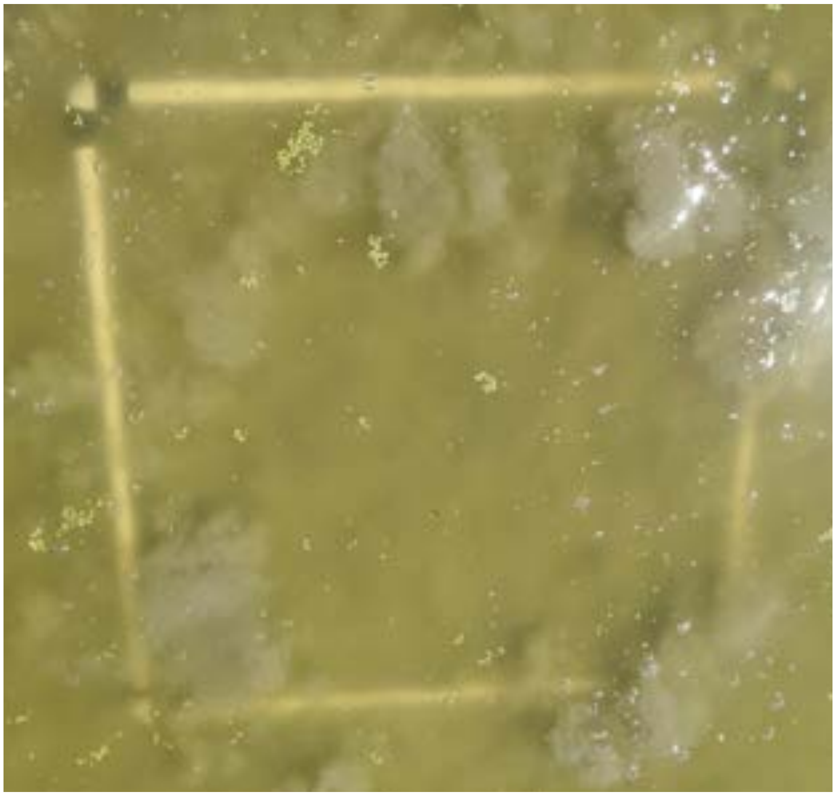


Figure 4A-(7/20) Vegetation Estimation. 1% Vegetation coverage

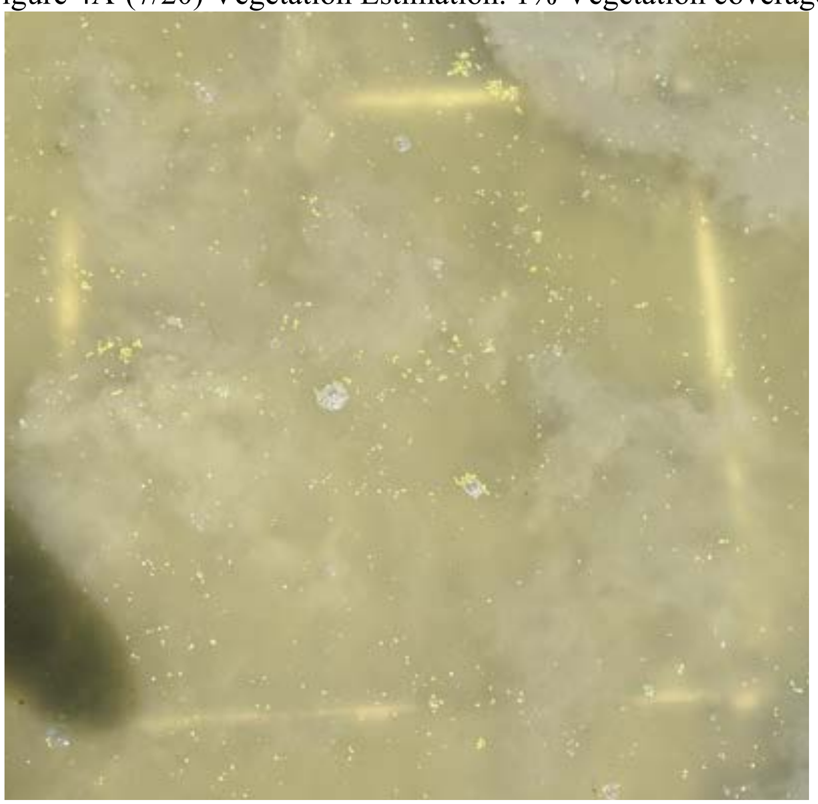


Figure 4A-(8/20) Vegetation Estimation. 1% Vegetation coverage

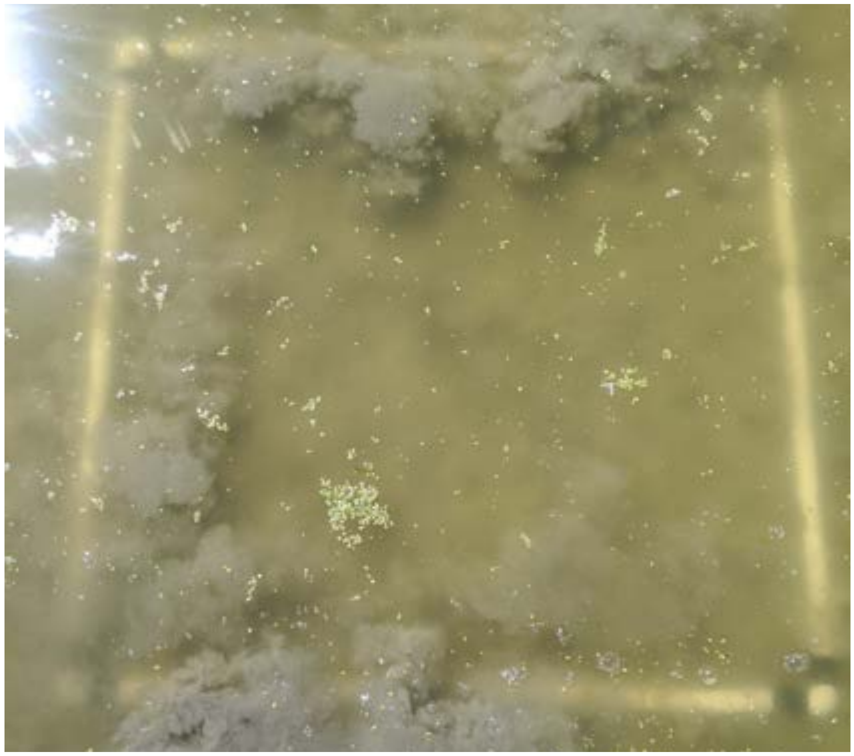


Figure 4A-(9/20) Vegetation Estimation. 1% Vegetation coverage

Figure 4A-(10/20) Vegetation Estimation. 5% Vegetation coverage

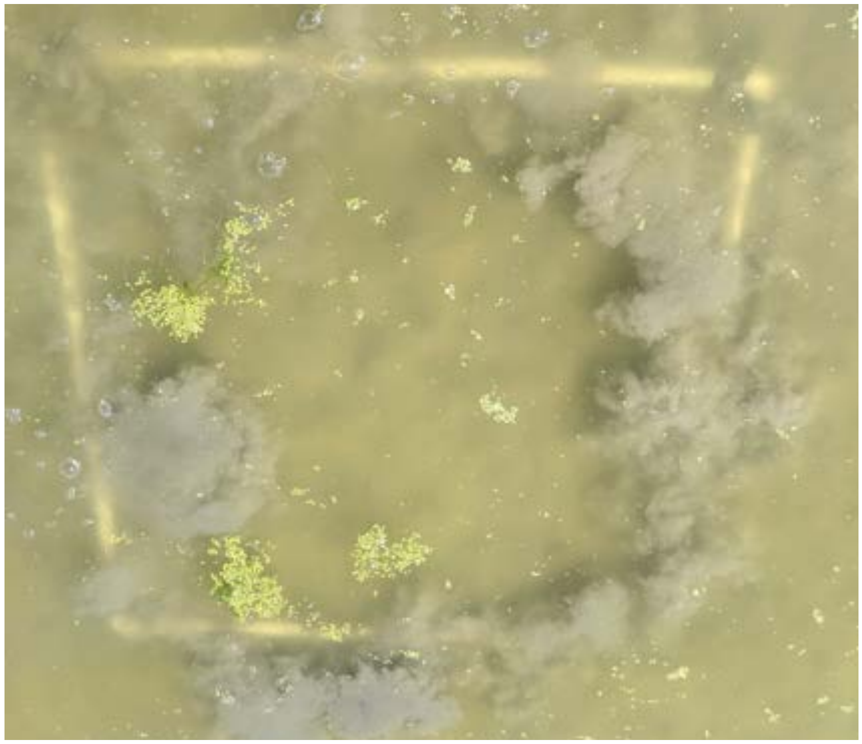


Figure 4A-(11/20) Vegetation Estimation. 5% Vegetation coverage

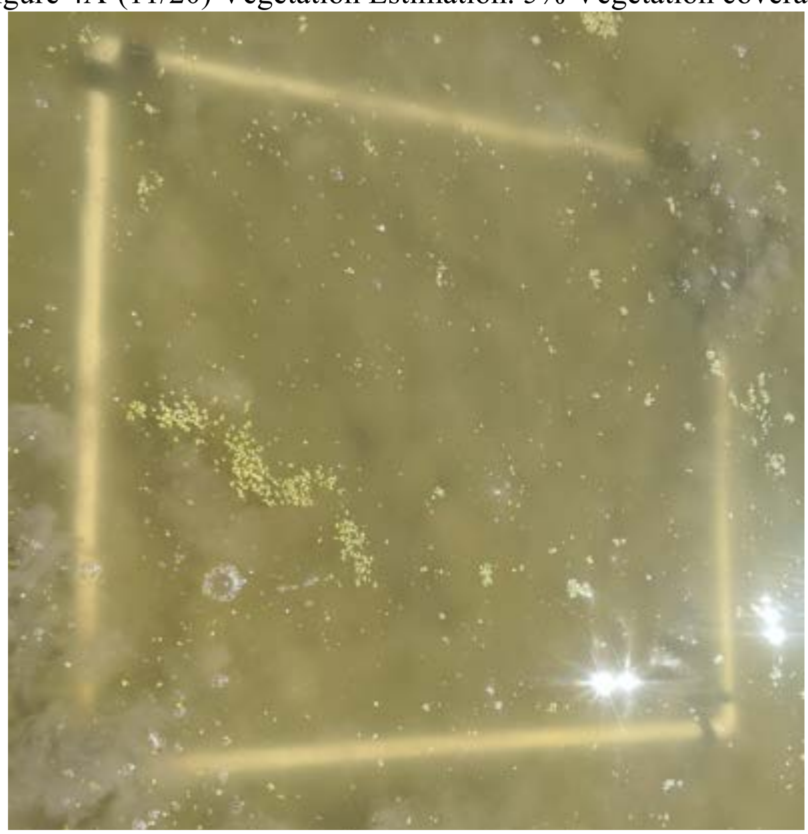


Figure 4A-(12/20) Vegetation Estimation. 1% Vegetation coverage

Figure 4A-(13/20) Vegetation Estimation. 10% Vegetation coverage

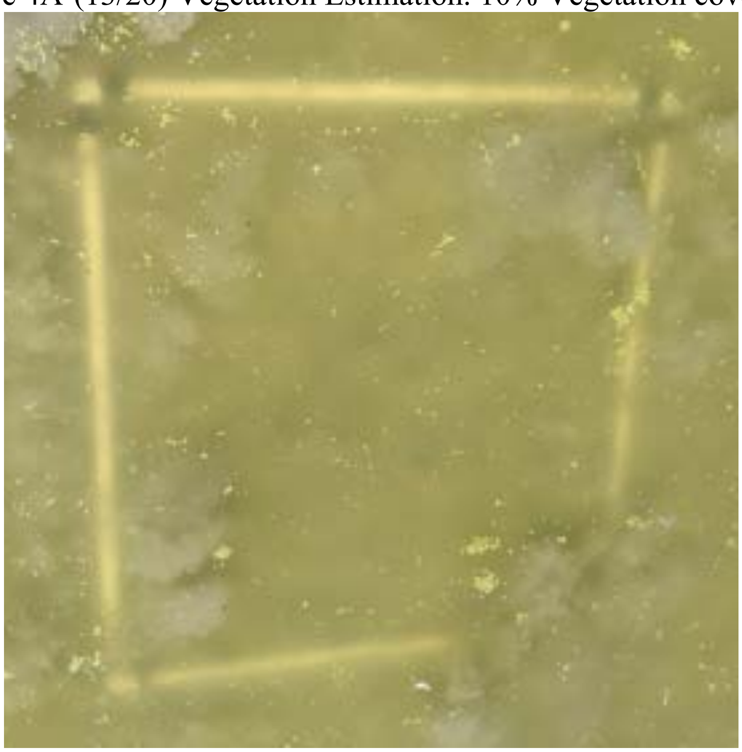


Figure 4A-(14/20) Vegetation Estimation. 1% Vegetation coverage

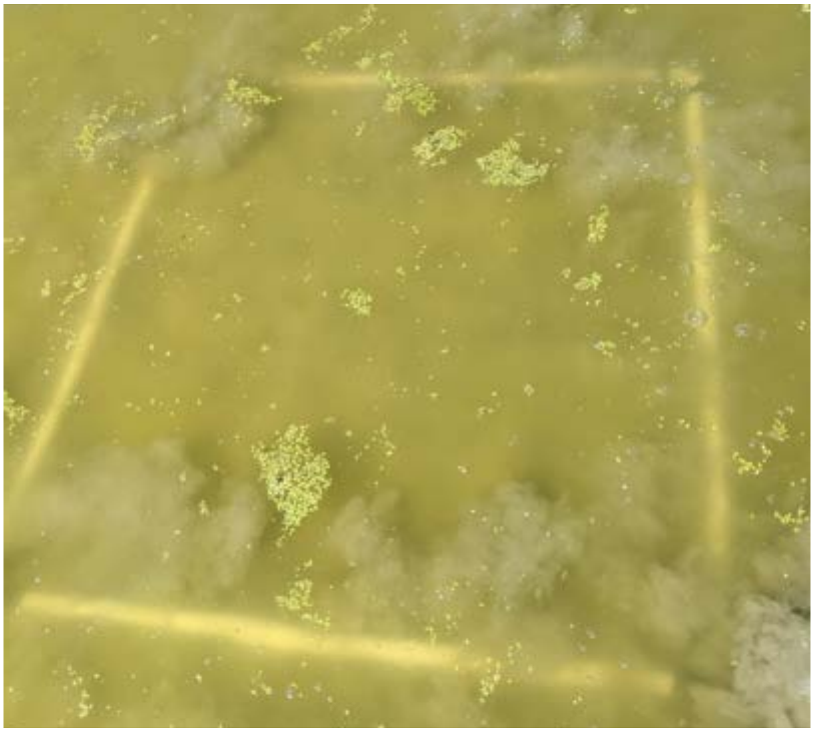


Figure 4A-(15/20) Vegetation Estimation. 5% Vegetation coverage

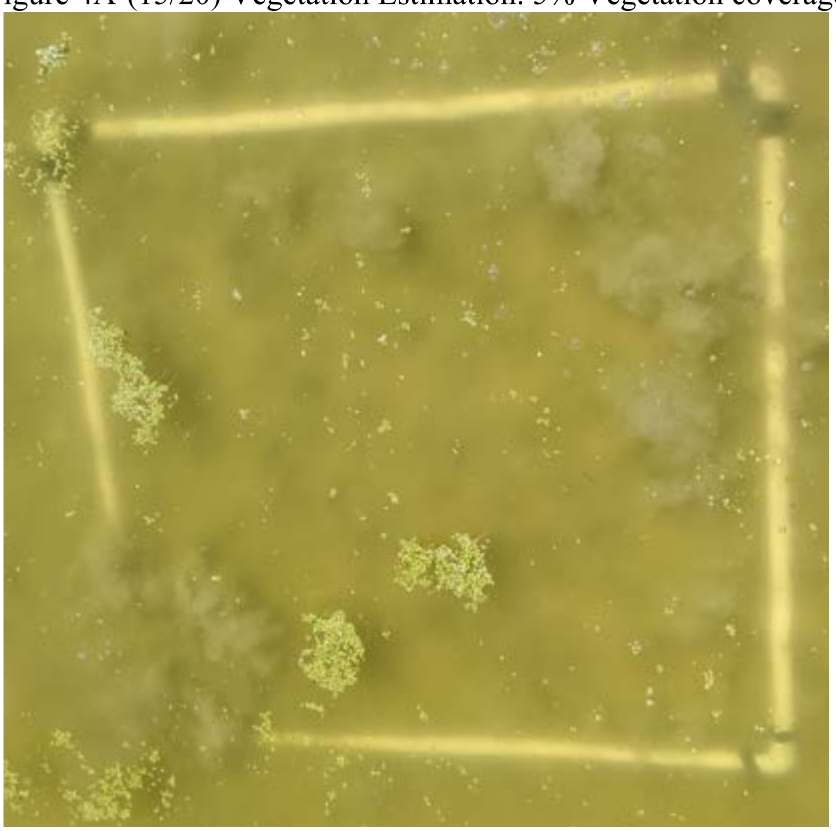


Figure 4A-(16/20) Vegetation Estimation. 5% Vegetation coverage

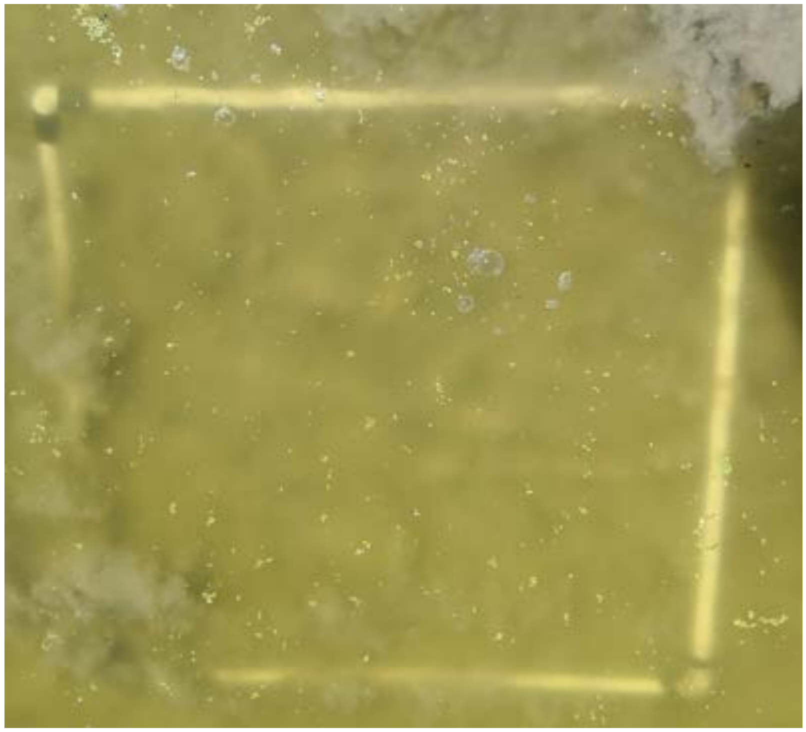


Figure 4A-(17/20) Vegetation Estimation. 1% Vegetation coverage

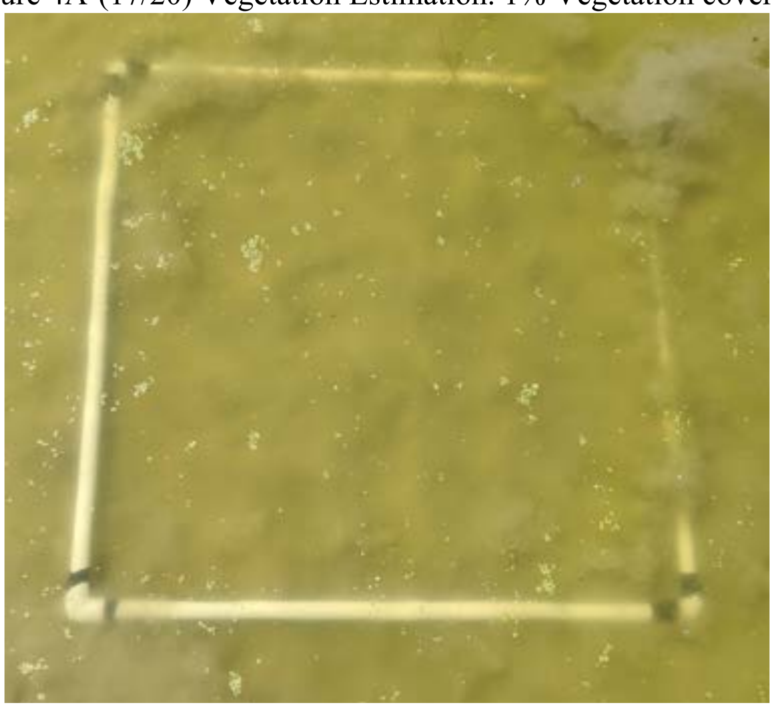


Figure 4A-(18/20) Vegetation Estimation. 1% Vegetation coverage

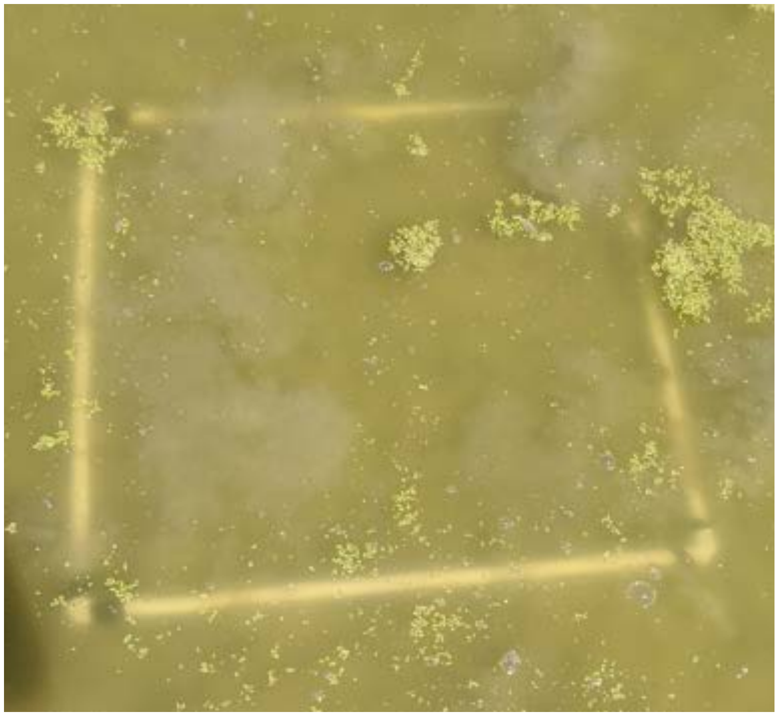


Figure 4A-(19/20) Vegetation Estimation. 5% Vegetation coverage

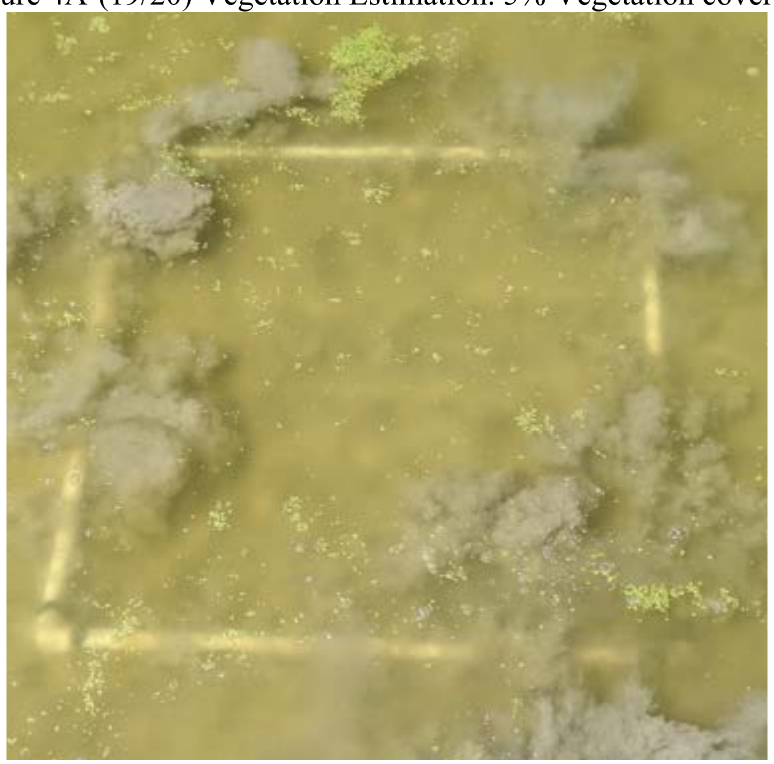


Figure 4A-(20/20) Vegetation Estimation. 5% Vegetation coverage