LADI and the Trawl

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Figure 1: From left to right: Emily Wells, Max Liboiron, Coco Coyle, Melissa Novaceski. Deploying LADI for trawling. Image credit to MEOPAR.

Executive Summary

This report details the design, construction, testing and validation of the Low-tech Aquatic Debris Instrument (LADI), pronounced “lady”, a tool which collects microplastics at the surface of the waer when towed behind a boat (called “trawling”). LADI is a smaller, less expensive, and easy to build alternative to the current scientific standard, the Manta Trawl, which is expensive and large.

Microplastics, plastics less than 5mm in size, account for over 92% of the plastics in the ocean [1]. However, scientists still do not have a thorough understanding of their origins, how and where they distribute in the ocean, and the true scale or consequences of their prensence. Trawls such as LADI and the Manta Trawl are one way to gather samples which provide data about the number, types, sizes, toxicity, origins, and more of the plastics at the water’s surface. Currently, the cost and size of the Manta Trawl limits its use to scientists with the resources to conduct a study. A smaller, cheaper, build-it-yourself trawl which produces the same type of data will greatly expand the number of possible users, not only to more professional scientists but to citizen scientists as well. Given the complexity of plastic’s presence in marine ecosystems, citizen scientists will be essential to building a truly global data set, and will also expand interest and activism on the oceans’ behalf. While cleanup technologies are bringing much needed awareness to the problem, compared to the size of the oceans and the micro-sized contaminants, coupled with ongoing pollution, they are simply not an efficient solution. Understanding the problems of microplastics, and expanding the data sets and communities involved in research, are the first steps in developing more effective solutions. We developed LADI to aid in this purpose.

It costs about $500 to build LADI with simple handtools. To use her, take her out on the water, attached to an arm on the side of a boat. Conduct as many trawls of 5-30 minutes as you need. Record the time, speed, and distance travelled. When finished with a trawl, thoroughly clean out the net into a sample container, which you will then take back onshore to study the contents under a microscpe. Record the number, size, and types of plastics found. This information will give you a good idea of what plastics are in the waters of that area.

Figure 2: LADI collecting plastic samples at Petty Harbor, Newfoundland. All images in this report were taken by a team member unless otherwise noted.

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1 Introduction

1.1 A Note on Language

It is traditional in a technology report such as this to use certain hallmarks of 'good scientific reporting,' such as using the third person point of view, passive voice, and minimizing focus on errors, personal thoughts, and qualitative analysis. The intent of this is to create an air of objectivity, to remove the author or authors' intentions and values from their work.

Civic Laboratory for Environmental Action Resaerch (CLEAR) is a feminist lab, founded on principals of equity, justice, and engagement with the communities and people that our work effects [2]. Instead of seeing science as an objective practice unassociated with society, feminist scholars recognize that scientific practice is grounded in the values and structures of those in power who created western, patriarchal society[3][4][5]. Thus we have a science which reflects this greater power structure, including the goals, leaders, and practitioners of the contemporary scientific community from its birth to the present day [21] [22]. Scientific 'objectivity' is not truly so, for by assuming a position of non-responsibility, the majority's practices and points of view are reinforced, while others, often those who are non-white or female, are minimized.

As part of my research with CLEAR in the summer of 2016, I organized a weekly reading and discussion group about feminist science and technology. Since it is the feminist perspective that objectivity cannot be reached, I believe it would be unethical and injust to myself, those who participated in passionate discussion with me, and CLEAR, to write in the 'traditional' manner. Thus I use first- and second-person perspective throughout this document, and include qualitative analysis and thoughts wherever I feel it is relevant; not out of ignorance, but out of devotion to the betterment of science and her many lovers.

Where I worked alone, I use the singular. Where two or more members of the team worked together, I use the plural. Similarly, the author ordership is determined as per the lab's "Equity in Author Ordership" guidelines [6].

1.2 Contributions

Coco Coyle: Project leader, author of this technology report excepting Sections 4 and 5, participant in all design and construction of LADI, and sewing the plankton net; all testing and validation events; sample and data analysis.

Melissa Novachevski: Author of Section 4, participant in construction, testing and validation, sample and data analysis.

Emily Wells: Author of Section 5, participant in construction, testing and validation, sample and data analysis.

Max Liboiron: Project advisor and supervisor, provided essential organization and networking, provided training and resources for deployment and analysis, lab and work space, and supplies, participant in all design and testing and validation events.

1.3 Background

It is no surprise that use of plastic material has exploded since their introduciton to mass production systems in the 1940s and 50s. Plastics can be substituted for many traditional manufacturing materials, are cheap and easy to produce and shape, and can be chemically modified to suit many purposes. Most plastic products are designed to last for a long time, yet many, such as packaging or disposables, are single-use only. For example, a plastic bottle takes an average of 450 years to completely degrade, yet is usually thrown out a few hours after purchase [7]. And products made from polyethylene terephthalate (PET or PETE) never biodegrade [7]. It is diffucult to recylce plastics, and only about 5-10% of disposed plastic is recylced, with and estimated 45% of disposed plastics becoming "lost to the environment" [8][24]. Of what's thrown away, much of it– estimates include about 10%[9] or 8 billion tonnes a year[10]–is eventually washed, blown, or dumped into the ocean. Once there, they are broken into smaller and smaller pieces by sunlight, erosion, and weathering, but never disappear.

An estimated 5.25 trillion piece plastics that occupy every ocean on the planet [1], with an untold amount below the surface [10]. Nearly 93% of them are smaller than a grain of rice [1]. Some common types of these microplastics (plastics smaller than 5mm) include microbeads (a common ingredient in toothpastes and face scrubs), threads (from fishing line or nets), microfibers (from synthetic fabrics, even smaller than threads), fragments (from macroplastics such as toys, water bottles, etc.), and film (such as pieces of plastic bags, or dryer sheets). Appendix B has some examples and pictures of these. Plastic pollution threatens a wide range of marine biota. While birds, fish, turtles and other large animals can become entangled in large plastics, much more common are threats from the ubiquitous microplastics. A wider range of organisms, from plankton to large mammals, can interact with microplastics, and studies are beiginning to indicate that microplastics are so pervasive as to litter remote and previously untouched locations including Arctic ice and the deep seafloor [9].

Many scientists and enironmental activists are concerned about the potential toxicity of microplastics. Plastics are good at absorbing certain kinds of chemicals, such as additives used in manufacturing, and these chemicals can leech from plastics into an organism which consumed them [23][25]. Scientists have only recently started to investigate the seriousness of this contamination and the harm it may cause to ecosystems and food chains, including human health [9].

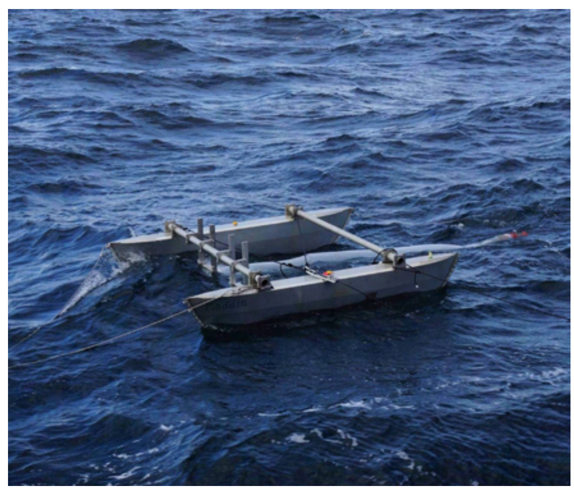
Plastics were first detected in the oceans in the 1970s [9]. Many have made estimates based on limited smapling and data sets, but the field of marine plastics pollution is still severely hampered by lack of saptial and temporal data sets [9]. Between the vastness of the ocean and the miniscule size of most plastics, it is extremely difficult for scientists to track their distribution around the global oceans. While some have rallied around creation and use of cleanup technologies and events, such as The Ocean Cleanup's prototype of a floating barrier [11], or the Ocean's Conservancy's International Costal Cleanup Day [12], these cannot compete with the scale of the problem and the constant introduction of more debris into the marine environment. More data, from more scources, is necessary before we start to develop more effective solutions.

Currently, there are only a couple standard tools for collecting samples of ocean plastics at the surface:

> "Because of their relatively low concentrations in the environment sampling of microplastic particles generally requires large sample volumes. Thus, samples from the open water are usually taken with plankton nets of different mesh sizes. The sea surface is sampled for floating microplastics by manta trawls (Eriksen et al. 2013a, b; Doyle et al. 2011) or neuston nets (Mort-Ferguson et al. 2010; Carpenter and Smith1972; Colton et al. 1974). While neuston catamarans (Fig. 8.1a) can be operated even in higher waves, a manta trawl (Fig. 8.1b) is best used in calm waters to prevent hopping on waves and damage to the device." [9]

These devices are called trawls, and are used by being towed behind a boat to collect samples, called trawling. The Manta Trawl, designed by Marcus Eriksen, and Catamaran Trawl, shown in Figures 3a and 3b show these. Appendix A shows the design drawing for the Manta Trawl, which is available for sale and as a loan from 5Gyres, a nonprofit organization dedicated to "empowering citizens to become leaders in combating the global health crisis of plastic pollution" [13][14].

(a) The Manta Trawl, at Petty Harbor



(b) The Nuestron Catamaran Trawl. [26]

Figure 3: Existing Trawls

These trawls are great for scientists who want to take large samples, do long trawls, intend to use the trawl frequently or over many years, or who need to take many samples on a long voyage. The trawls are very sturdy and need little maintenance. They are made of aluminum and require welding and other advanced metalworking skills and tools to make. However, this also makes them difficult and expensive to produce; our team ordered a custom-made 'mini' version of the Manta Trawl, costing us 3500 USD. They are also quite large and heavy, and not easy for one person to transport and use. While a good and sturdy piece of scientific equipment, because they are currently the only scientific tool capable of producing valid data about surface water microplastics, the audience for their use is limited to those with plenty of money and other resources.

Thus it is important to develop tools which produce equivalent data, but are cheaper and smaller, and serve a wider audience. Another important consideration is that could be constructed with simple tools, tools that most households have on hand. This will reduce cost, allow people to customize their own trawls, and include citizen scientists in the research.

Citizen science, one of the founding principals of CLEAR, is characterized by people without scientific degrees participating in scientific research. This ranges from citizen data collection, to collaboration between citizens and scientists for the duration of a study. This is an incredibly advantageous technique for expanding research, promoting hands-on education, and more methods for individuals and communities to ask and answer their own research questions. Citizen scientists can produce data that is affordable and extensive, while simultaneously engaging the public in scientific study. Overall, citizen science complements the current climate of ecological monitoring, including plastic research.

CLEAR believes citizen scientists as well as feminism, equity, and justice are important parts of good scientific practice. LADI is designed to fill a hole in the field of marine plastics monitoring, and to further CLEAR's goals and values.

1.4 Problem Statement

The team was tasked with designing, implementing, testing and validating, a trawl to be used for collecting microplastics at the ocean's surface when towed behind a small ocean vehicle. The trawl's counstruction should require only materials and skills that a person with a limited budget without access to specialized equipment would have.Delivarables include the trawl, samples and data analysis from validation, and written instrucitons and a technical report suitable for open source publication. All of these are included in this report.

2 Design

2.1 Functions, Objectives, Constraints

With the problem statement in mind, we developed following Functions, Objectives, and Constraints to specify the requirements and values of the device.

Functions
The device needs to:

- Skim the surface of ocean water in still or choppy water
- Always have the top edge of the mouth above the surface of the water, and always the other edge below.
- Collect microplastics in a detachable capture device (known as a cod end)

Objectives
The device should be:

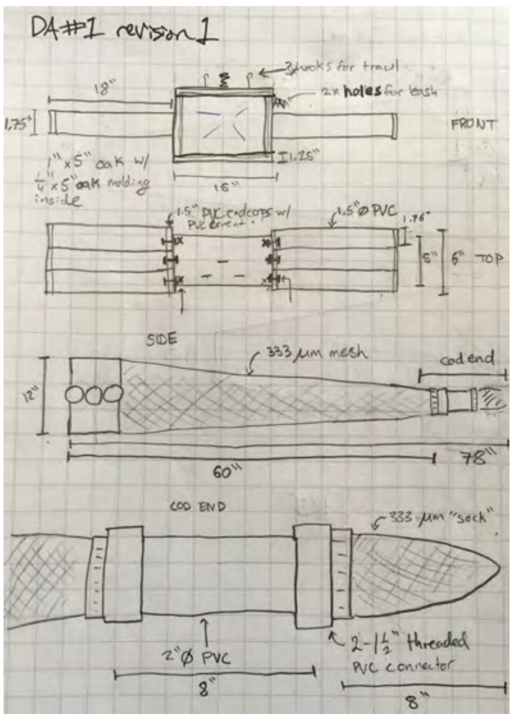
- Easy to construct, maintain, and troubleshoot
- Reusable
- Robust
- Easy to carry and transport
- Cheaper than scientific standard, the Manta Trawl
- Comarable with the Manta Trawl in quantity and quality of data collected

Constraints
The device must:

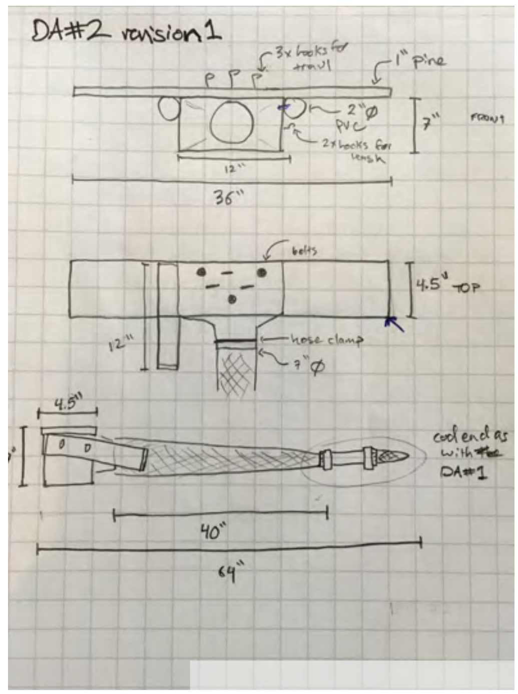
- Use a 333 μm (micron) mesh net
- Have a rectangular opening
- Weigh $\leq$20lbs
- Cost <CAD$500
- Withstand trawling speeds least up to 5 knots
- Be leashed on two axes to the side of the trawling vessel

- Use only materials found in non-specialty stores or online
- Be made with hand tools

We developed two major design alternatives, one original design dubbed the Low-tech Aquatic Debris Instrument (LADI, pronounced "lady"), and another which was a modification of a previous design by Marcus Eriksen, which he shared with the team, called Manta Jr. (Figure 5). While this report primarily concerns LADI, we built and tested both designs in order to asses which design better satisfied the problem statement. Figure 4 shows initial sketches for both design alternatives. A CAD drawing for LADI is shown in Figure 7, on Page 16.



(a) Early design sketch for LADI



(b) Early design sketch for Manta Jr.

Figure 4: Early sketches of LADI and Manta Jr.

(a) The prototype uses a metal vent for a mouth.

(b) The prototype uses a paint strainer as a net.

Figure 5: Marcus Eriksen's Manta Jr. prototype. Images courtesy Marcus Eriksen.

There are a number of important considerations that went into the design of LADI. Oak wood is used for the mouth because it is a hardwood and warps less that a softwood, yet is still less dense than fresh and salt water [15]. Oak molding is used to firmly and tightly attach the net to the mouth at many points, spreading the drag force on the attachment points over the entire net opening, greatly reducing the risk of tearing the holes in the net where the bolts pass through. There is also nylon reinforcement at every net's opening for the same reason. I chose molding because it is strong enough to be bolted to the thicker outside frame, but does not add as much weight and is more hydrodynamic.

The wings are made of three PVC pontoons, which are waterproofed and provide additional floatation. The wings are in the vertical center of the body, so that the trawl may travel through choppy water and the surface of the water remains within the mouth at all times. The length of the wings keeps the mouth of the trawl steady in the water and prevents the trawl from spinning or flipping. The wings are also slightly angled upwards, towards the front, which produces lift which is especially noticed when trawling at higher speeds (above 3 knots). Otherwise, the trawl would tend to pull downwards into the water, due to drag forces on the net. The pontoons are strapped together with woven rope, which strengthens them, creating one solid out of the three pontoons. This also reduces stresses on the pontoons' attachment points to the body as well as reducing vibrations in each pontoon.

The net is made with the standard size mesh used in other microplastics trawls (333 microns). You could make LADI's net by purchasing a ready-made net or some mesh, and sewing your own net. Making your own net allows one to sew it with a 'double seam' which eliminates a crease along the edge. Every crease inside the trawl is an opportunity for microplastics to be trapped and not included in the sample, affecting the results. The cod end (the very end of the trawl, atttached to the net with hose clamps and a piece of wide PVC pipe) has two creases on the side, but is designed to be invertible through the PVC connection, so that plastics caught in this crease can still be collected with a spray of water to relese them.

Manta Jr.'s original design calls for an air conditioning duct as a mouth, a paint striner for a net, and a wood plank for wings. The paint strainer is cheaper and easier to find than a plankton net, but may not be fine enough to catch many microplastics. In our redesign of Manta Jr., we added a plankton net, lengthened the wings to about 4' for stability, and added two pontoons to the side of the duct for added floatation and to direct the trawl forward.

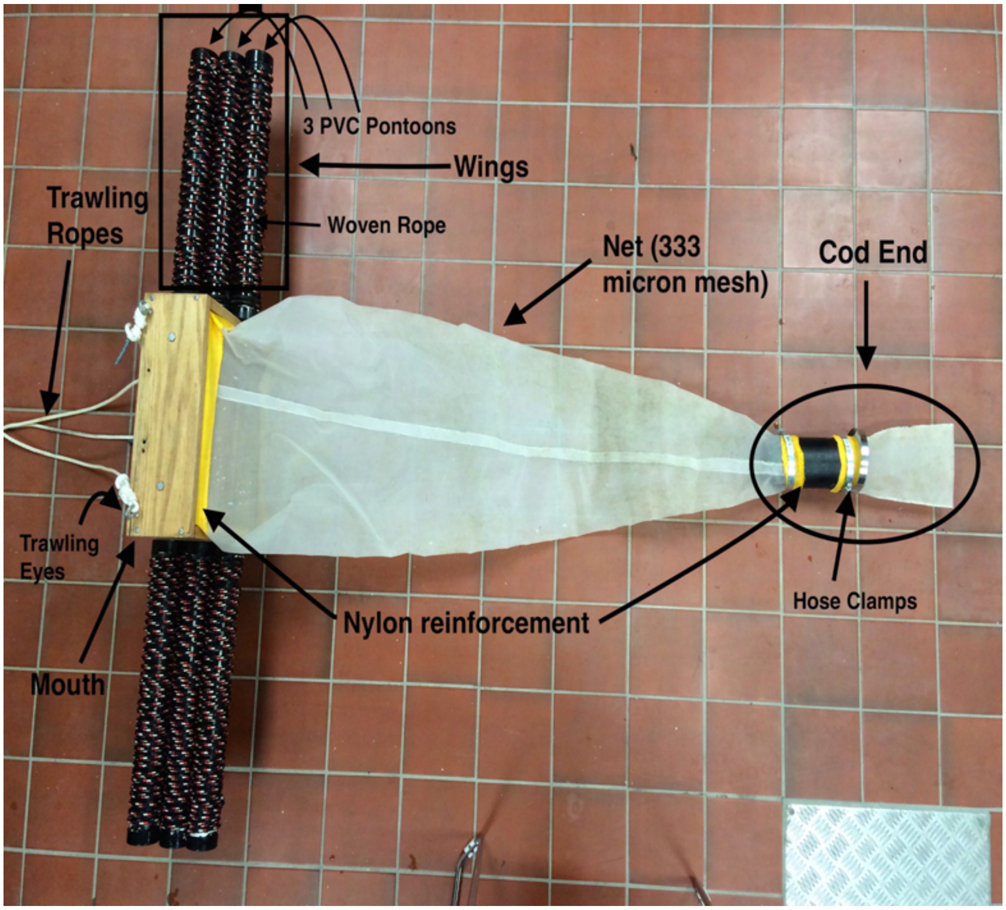


Figure 6: A completed LADI trawl, with parts labeled.

Best of Class Chart		
Function	**LADI**	**Manta Jr.**
Skims surface	4	1
Collects microplastics	4	1
Objectives		
Be easy to construct...	3	4
...maintain...	4	4
...and troubleshoot in the field	3	2
Be robust	4	2
Be reusable	5	5
Be relatively cheap	3	4
Be easy for one person carry and transport	3	3
Totals	33	26

Legend:
√ = Success
1 = Poor …. 5 = Excellent

Constraints		
Must use a 330 or 333 μm net	√	√
Must have a rectangular opening	√	√
Must be ≤ 20 lbs	√	√
Must be able to construct for $\leq$ \$500 CAD	√	√
Must be able to withstand being trawled at up to 5 knots	√	N/A
Must be leashed on two axes to the side of a boat	√	√
All materials must be able to be sourced in non-specialty Canadian stores or online	√	√

Table 1: Best of Class table for LADI and Manta Jr.

2.2 Best of Class Chart

To compare how well each design satisfies the functions, objectives, and constraints, I made a best of class chart (Table 1) using information gathered during construction and testing (See Sections 3 and 6). For each function and objective, I ranked each design alternative's performance from 0-5, with 0 representing failure to fulfill and 5 representing complete satisfaction. The constraints were ranked on a binary basis; failure to fulfill any of the constraints is an automatic failure of the instrument.

After testing in both open ocean and controlled flume tank conditions, LADI better satisfied the functions and objectives than Manta Jr., with a score of 33 compared to 26. The rest of this report focuses on LADI's construction and validation.

3 Construction

3.1 Overview

The instructions presented here are intended to provide a basis to building your own LADI or a variation on this design. Though they are in-depth in order to be useful for as wide an audience as possible, many of the details can be altered to suit your needs. Some materials may be substituted for others, and those which cannot are explained in the following section. Directions are given to follow the dimensions specified in the diagrams in Figure 7, however, LADI is easily scalable, within certain limitations. These limitations are explained in Section 3.8. Be sure to read all of the directions before getting started.

3.2 Materials and Costs

Table 2 shows the required materials and construction costs of LADI, based on the materials we used during construction. In addition to these supplies, the following tools are required: measuring tape, a hand saw, sewing machine (if you are making your own net), electric drill, coarse grit sandpaper, nut driver, 1/4" wrench, scissors, and a caulking gun. If possible, the following tools are recommended but not necessary: PVC cutter, power saw, orbital sander or dremel tool.

Remember to budget for shipping and taxes based on your location. As a reminder, these costs are calculated in Canadian dollars bsaed on local prices at the time of construction (June 2016, in St. John's, Newfoundland) and are intended as a guideline, not a promise.

Legend:
D Diameter
r Radius
L Length
W Width
m Meters
cm Centimeters
" Inches
′ Feet
μm microns or micro meters (10^{-6} meters)
mL Mililiters

Some notes and tips from the table:

1. The first and most significant choice is to decide whether you will build your own net, or buy one. To sew your own net, you will need to puchase a couple meters of 333 μm mesh online; this is a very small net size (often referred to as a plankton net) and is necessary for catching microplastics. The other option is to buy a Bongo Net, which has the same size mesh but is delivered already in the form of a net. Though the mesh alone may be more expensive depending on your location and source, I find it preferable in certain cases, however the choice will ultimately depend on your budget and the dimensions of your trawl. Some points to consider:

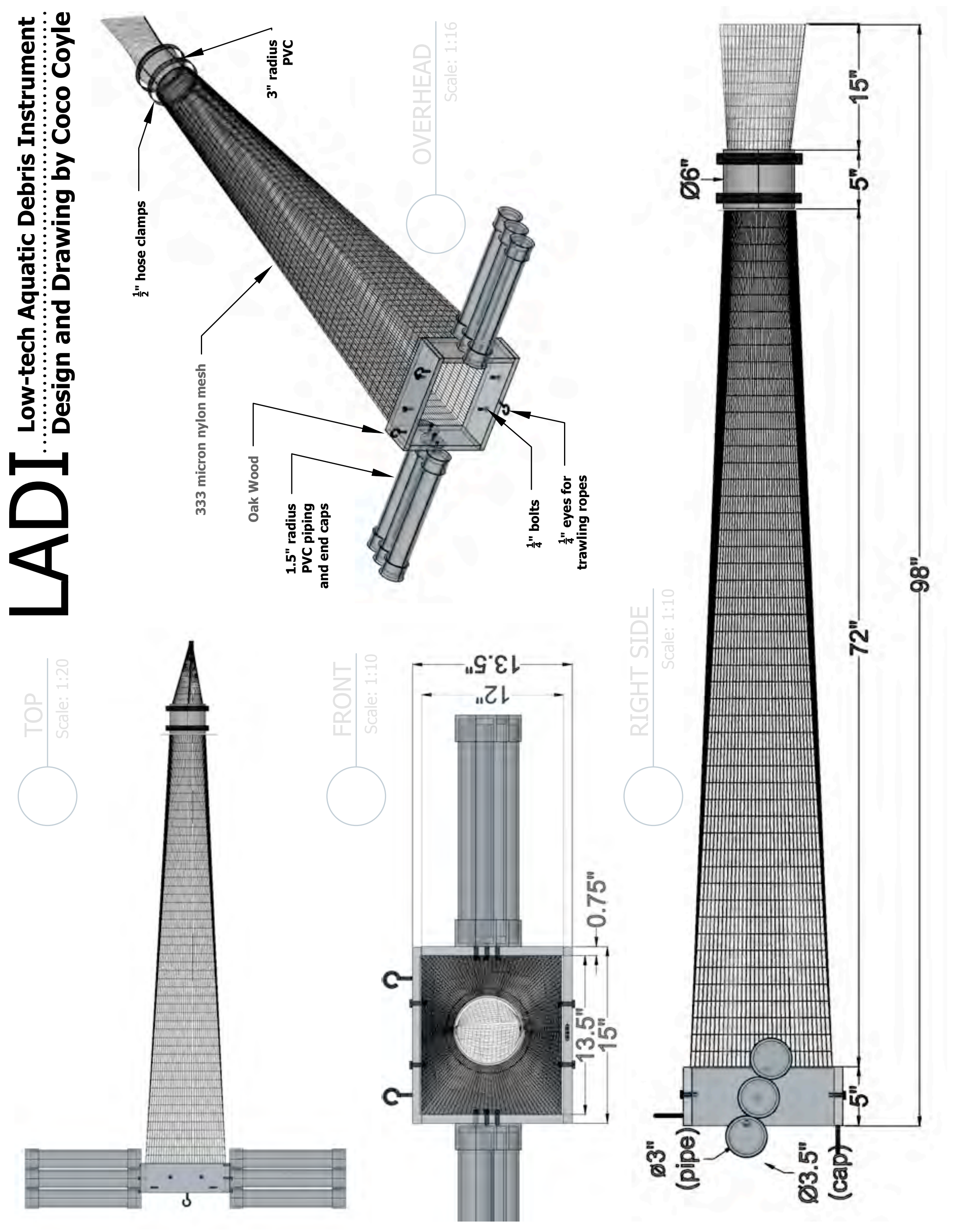


Figure 7: Conceptual drawings of LADI

Item	Amount/Specs	Price (CAD)	Source
333 μm mesh	2*m L* x 1.68 *m W* (79"*L* x 66"*W*)	370.00	Halltech Aquatic Research Inc.
Bongo Net[1]	50*cm D* x 150*cm L*, 333 μm mesh	210.00	Aquatic Research Instruments
Nylon Ripstop Fabric[2]	1*m* or 1 yard	5.15	Online Fabric Store (or local fabric store)
PVC pipe	4 3'*L* x 1.5"*r*	20.72	Home Depot
PVC pipe[3]	3' x 3"*r*	14.77	Home Depot
PVC caps	12 1.5"*r*	41.16	Home Depot
PVC cement, premium grade[4]	1 small can, 473 *mL*	7.48	Home Depot
Silicon Caulking/Sealant	1 bottle	6.97	Home Depot
Oak wood[5]	1"*H* x 5"*W* x 6'*L*	25.95	Home Depot
Oak molding	5"*W* x 6'*L*	21.00	Home Depot
Thompson's WaterSeal, Wood Waterproofer[6]	1 small can	12.97	Home Depot
Wood Screws[7]	8 0.164"*D* x 2"*L*	1.00	Home Depot
Eyes	3 ¼"*D* x 2"*L*	1.53	Home Depot
Bolts	4 ¼"*D* x 1.5"*L*	1.48	Home Depot
Bolts	6 ¼"*D* x 2"*L*	2.40	Home Depot
Nuts[8]	10 ¼"*D*	1.20	Home Depot
Rope	2 ¼"*D* x 100'*L*	21.48	Home Depot
Hose Clamps	2 3"*D* or 4"*D*	2.98	Home Depot
TOTAL:		398.24 - 558.24	

Table 2: Materials and Costs for construction of LADI

- If you purchase mesh, you will be able to make a custom net suitable for the size of your trawl, and the desired length.
- To use a Bongo net, you may have to change the dimensions of the trawl to match the net diameter, instead of the other way around. The maximum net mouth diameter available from Aquatic Research Instruments is $50cm$, the equivalent of a 62" circumference (a bit bigger than our design, which uses a 53" circumference net)
- Mesh may be more expensive, and making your own net requires a sewing machine and additional time.
- In our case, which may or may not be representative, Halltech Aquatic Research Inc. proved to have superior customer service and delivery time for the mesh than Aquatic Research Instruments did for their net (3 weeks as opposed to 8 weeks).
- The Bongo net is not designed for use on a trawl, and requires a few additional alterations (Section 3.8)
- Most Bongo Net do come with a cod end, which will be designed for catching plankton, but be sure to check your source does have one if you intend to use it.

2. Other subsitutions may be made instead of purchasing new nylon ripstop fabirc; I used a secondhand rain jacket for no cost; other windbreakers, tents, sailcloth, and similar materials may be used. This material is used to prevent tearing or snagging of the mesh, so use your intuition to determine if a certain material would provide such protection.

3. You only really need about 4-6" of the larger diameter PVC to make the cod end. A larger diameter may also be used; I recommend 3"r minimum becuase it is possible to invert the cod end for quick and easy sample collection.

4. We initially used a medium grade PVC cement and it proved inneffective at preventing leaks and holding the PVC together, so a premium grade really is necessary.

5. Oak is recommended because it is a sturdy hardwood and does not warp as much as other woods in water, which could affect your calculations.[15]

6. The same 1/4" nuts may not fit both the 1.5" bolts and the 2" bolts; the threading may be a different size. Be sure to check before buying that you have the right kinds of nuts for both. Don't be fooled like we were!

7. I reccommend starting with a basic, paint-on wood stain/sealer combo, then applying a waterproofing on top of that. Salt water and various marine organisms can easily set up camp in the wood grain, so a few layers of protection will help. You will also want to wash off the trawl with fresh water after use to prevent molding.

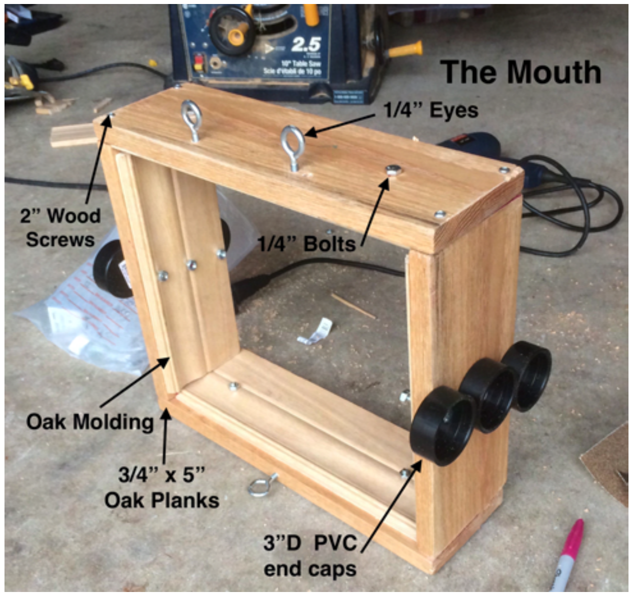


Figure 8: The completed mouth.

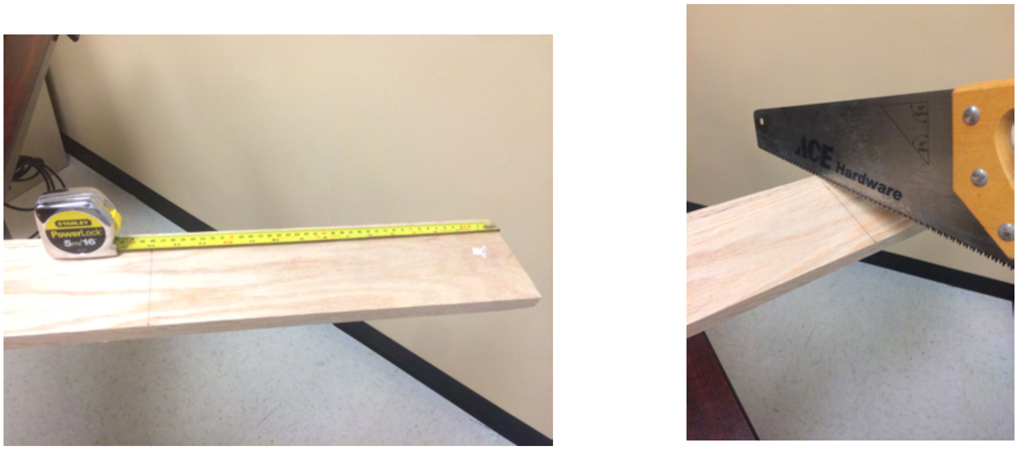
3.3 Constructing the Mouth

For this section, you will need:

- 1"H x 5"W x 6'L oak wood
- 5"W x 6'L oak molding
- Wood Stain/Sealant and Waterproofer
- 8 x 0.164"D x 2"L wood screws
- 6 x 15"r PVC end caps
- 3 x 1/4"D Eyes
- 4 x 1/4"D x 1.5"L Bolts
- 6 x 1/4"D x 2"L Bolts
- Drill
- Saw
- Sandpaper or Sander
- Wrench
- Measuring tape

Estimated time: 4-8 hours of work, 3+ days for drying

1. Begin by measuring two 15" and two 12" pieces of oak. You may wish to give yourself an extra 1/8" or so for sanding, especailly if you are using a handsaw.



(a) Measure twice, cut once.

(b) Cut carefully and use a partner!

Figure 9: Step 1: Measuring and cutting oak for the frame.

Double- and triple-check your measurements before cutting. Always have a partner with you when using a saw, as well as appropriate safety equipment. After cutting the pieces, sand all the ends and edges. Make sure there are no splinters or jagged edges, which can snag and damage the net during use.

2. Using your stain/sealant or waterproofer, coat the wood once and let it dry completely (check the instructions on your product for drying time. Some may 48 hours). If you have a stain and a waterproofer, stain first and let it dry completely before applying a waterproofing to the wood. Make sure you get an even coating on your wood, and work in a well vantilated area.

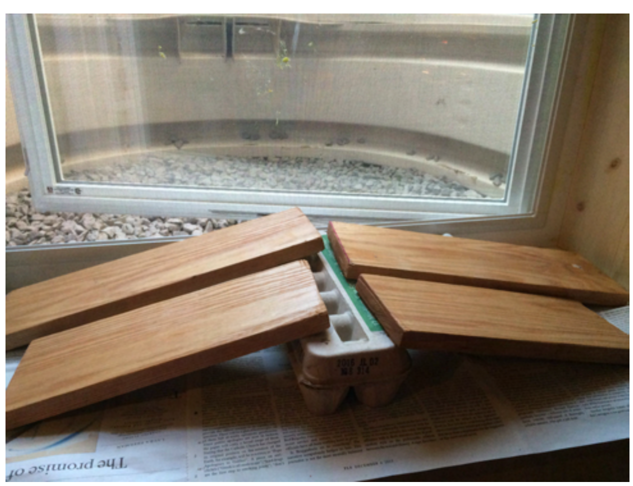


Figure 10: Step 2: Drying a coat of waterproofing on the oak frame pieces.

3. Use a drill and wood screws to construct the rectangle frame. Drill a smaller pilot hole before inserting the screw to avoid splitting the wood. The 15" pieces are for the top and bottom edges of the frame; the 12" pieces are for the left and right sides of the mouth. The 12" pieces go in between the longer boards as in Figure 11.

Figure 11: Step 3: Drilling pilot holes for woodscrews.

4. Measure the insides of the mouth to determine the exact lengths of the molding. Ours ended up being about 13.5" long for the top and bottom pieces, and 11.5" long for the left and right pieces, arranged in the same way as in the previous step (lef and right pieces between the top and bottom). These measurements may be different from the model depending on how accurately you cut and sanded the previous oak pieces, so be sure to check the fit.

5. Cut the molding pieces to length.

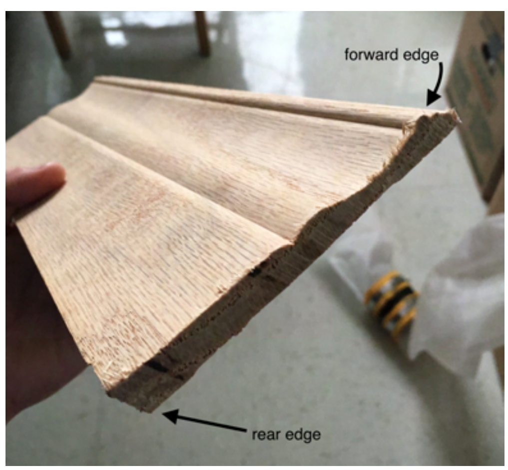


Figure 12: Step 5: The molding used for our LADI prototype.

6. Sand down the ends and edges of all the oak moudling pieces. Make sure that they fit together within the frame. The molding should have one smooth side and one flat

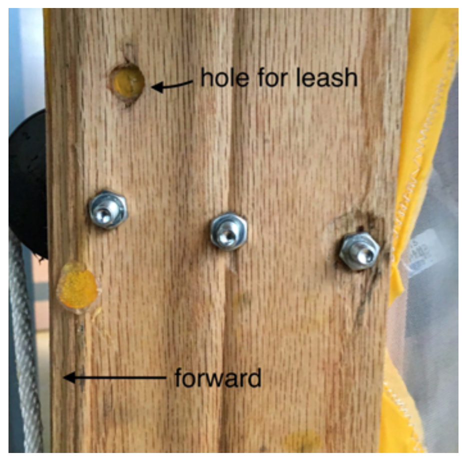
side, the smooth side should all face te same direction, which will be the 'forward' side of the mouth. They should not be shaky or rattling, but should be slide smoothly in and out.

7. Using your sealant or waterproofer, coat the wood and let it dry completely. Apply the second coating if you have one.

8. Drill holes for the bolts. The top and bottom (the longer sides) of the frame require two bolts each, on the centerline horizontally as viewed from the top, one about 5" from the left edge and the right edge each, as shown in Figure 13a. Use a clamp or have a partner hold the molding to the frame, taking care that their hands are not in danger of receiving an unanticipated piercing. Drill 1/4" holes here, insert 1.5" long bolts and tighten the nuts with the wrench. You may wish to use sandpaper or a dremel tool to remove splinters from around the hole. The bolts should not fit too loosely but should not be hard to insert.

9. Repeat Step 8 for the bottom of the mouth.

(a) Top of the frame, viewed from the inside (image not to scale. 5" is correct.)



(b) Left of the frame, viewed from the inside. Note the increasing angle towards the front of the frame, and the hole for leashing (Section 3.7)

Figure 13: Steps 8-14: Bolt locations on the mouth.

10. The left and right sides will have 3 2" long bolts each, which will pass through the PVC end caps, oak wood, net, and molding. First, find as exactly as possible the center of one PVC end cap, and drill a 1/4" hole. It is slippery to drill on plastic so take it slow at first and do your best.

11. Now measure and mark the center of the left side of the oak frame (horizonatally and vertically). Use a clamp or have a partner hold the molding to the frame. Drill a 1/4" hole, and sand or dremel the edges smooth.

12. Secure the cap, frame, and molding together with the 2" bolt. If it appears to be secure and centered, repeat steps 10 and 11 for the right side. These are the middle end caps.

13. Since the wings will be on a slight angle, you will need to determine which direction is forward. The next two end caps, on the forward side of the existing middle end caps, should be slightly above the centerline, as in Figure 13b. The exact positioning is up to you, however, be sure that you have enough space to drill holes (no closer than 1/2" to the edge of the frame) and secure all the pieces (for example, if you drill a hole in the end cap too close to the edge, the bolt will not fit straight). The holes in these end caps will not be in the center, with this exception, repeat the drilling procedure as in Step 10-12. These are the upper caps.

14. For the lower caps, repeat the procedure in the previous step, but slightly below the center line, and behind the middle end cap, as in figure 13b. Tighten all the nuts and bolts with the wrench.

15. The last step is to add the eyes for trawling. Two eyes are placed on the top of the mouth, as in Figure 14. They should be about 2" from the left and right corners, towards the forward edge. One eye is also placed on the bottom of the mouth, but on the front side of the frame (pointing forwards, not down) and in the center, so that the trawl can sit stably on a flat surface.

    You will need to drill holes slightly smaller than the thread diameter of the eyes, and no deeper than the length of the eyes' threads. For our eye screws, which were 1/4" diameter, we used a 3/8" drill bit, and used the wrench to tighten the eyes in.

    Be extra careful here: even a small misplacement of the eyes would affect the orientation of the trawl's mouth in the water

Figure 14: Step 15: Locations of the eyes used for trawling ropes

16. In the side of the trawl, just above the wings and towards the front, drill a large hole for leashing, marked in Figure 13b. We used a 1/2" drill bit, keep in mind you may need to work up to this size with a few smaller bits first. This leash is *only* used if the primary trawling ropes (attached to the eyes) fail for some reason; otherwise the leash does not bear weight. It is the emergency brake. We do not use an eye here because in the case of such an emergency the lease will be subject to a large impulse force and there is a chance that the eye would be ripped out.

17. Congratulations! You have finished the mouth of the trawl.

(a) The completed mouth.

(b) Team member Emily Wells, showing off her work

Figure 15: The trawl mouth, finished.

3.4 Constructing the Wings

For this section, you will need:

- 12' of 1.5"r PVC pipe
- 6 x 1.5"r PVC end caps
- 1 can of premium grade PVC cement
- 1 tube of Silicon caulking
- Caulking gun
- Saw
- Sandpaper
- Measuring tape

Estimated Time: 2-3 hours.

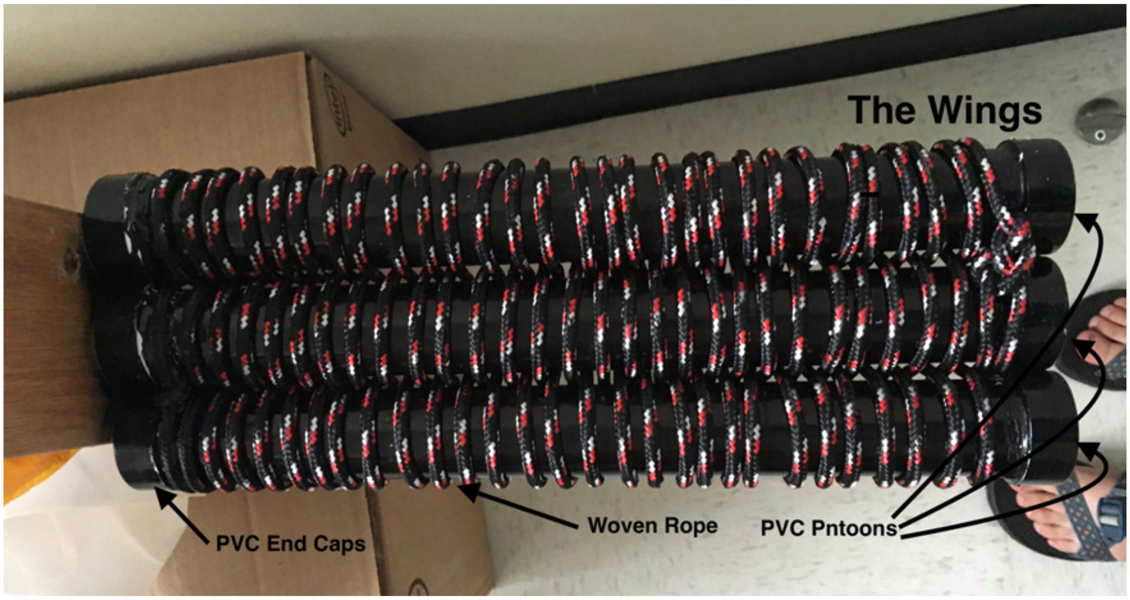


Figure 16: The completed wings.

1. Cut 6 x 18" long pieces of 1.5"r PVC pipe. A rubber band is an easy way to mark the cutting point on a circular black tube.

Figure 17: Step 1: Cutting the PVC pontoons.

2. Quickly sand the edges to remove any snags.

3. Clean both ends of the pipe with PVC cleaner (if you have it) or a dry cloth. To the outside one end of a PVC piece and to the inside of one end cap (new, not one on the mouth already), liberally apply PVC cement, then quickly press the two togetjer and twist them. Be sure they are on straight! Repeat this step for all 6 PVC pieces, leaving the other end of each pontoon open for now. Be sure to do this stpe in a well-ventilated area, and don't get and cement on your hands or clothes.

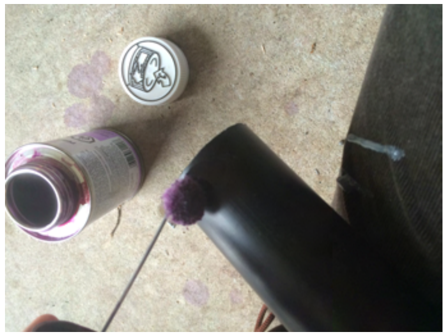


Figure 18: Step 3: Applying PVC cement to the pontoons.

4. On the mouth, with the silicon caulking and gun, apply a dab over the top of each bolt, inside the PVC caps (figure 19). This is to prevent water from leaking into the pontoons after it is sealed, so be sure to cover them completely and give them plenty of time to dry.

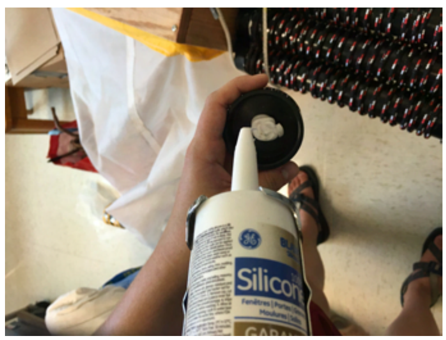
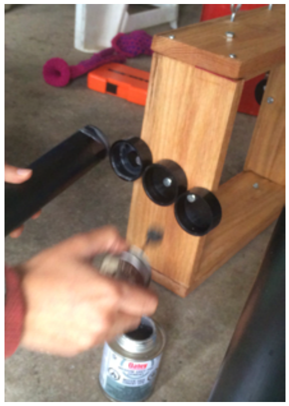
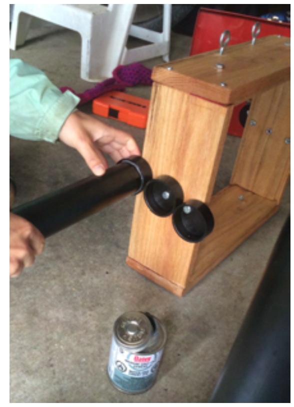


Figure 19: Step 4: Waterproofing the bolt-hole with silicon caulking.

5. Repeat the Step 3 to cement the pontoons to the end caps already on the mouth; you will need some boxes, books, or other support to hold the wings in place while they dry (Figure 20).



(a) Applying cement to the pontoons and end caps.



(b) Securing the pipe to the frame with a twist.

(c) Supporting the wings while they dry.

Figure 20: Step 5: Attaching the wings to the mouth.

6. When the cement is completely dry, use the caulking gun to apply a thick line of silicon around the seams between each end cap and pipe (Figure 21). Use a tool to smooth the silicon out and to ensure that it completely covers the crack. Do this for all 12 end caps.

(a) Applying cement to the inner PVC and end caps

(b) Securing the pipe to the frame with a twist

Figure 21: Step 6: Applying silicon caulking to waterproof the PVC pontoons

(a) A simple knot to anchor the rope

(b) A knot for the outer edge of the wings secures the rope

(c) The method of weaving the ropes between the PVC of the wings. Be sure to pull it tight at every step for a snug fit!

(d) The final product. Note the tight spacing of the ropes.

Figure 22: Steps 7-8: Securing the pontoons into wings with rope.

7. To strengthen the wings, we will wind ropes between the pontoons, tying them together and creating one solid wing. To start, take the end of a length of 1/4" D rope, and wrap it around one of the pontoons, on the end close to the body. Tie a knot to secure the rope as in Figure 22a, then begin weaving the rope between the PVC pipes, working outwards, using the method in Figure 22c. Constantly pull the rope tight to ensure a snug fit, the rope should be in fairly close rows, as in Figure 22d. You should feel the PVC getting stronger; it will get harder to push the rope in between the pipes.

8. Work until you reach the end of the pipes, then cut the rope leaving just a bit extra for a knot. Carefuly use a lighter to slightly melt the end of the rope and roll it into a tip, to prevent fraying. A piece of duct tape wrapped around the end will also work. Tie another knot to secure the end of the rope, for an example see Figure 22b. Repeat Steps 7 and 8 for the other wing.

9. Congratulations! You have finished the wings.

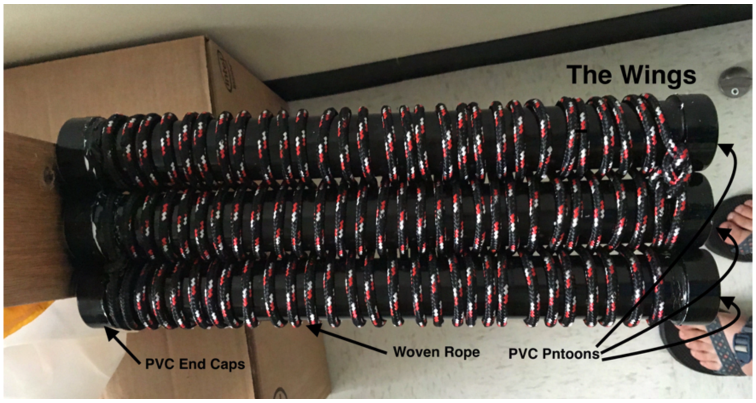


Figure 23: The completed wings.

3.5 Sewing The Net

For this section, you will need:

- 333μm mesh
- Nylon ripstop fabric
- Sewing machine
- Sewing supplies (thread, scissors, pins)
- Measuring tape
- Recommended: someone who knows how to use a sewing machine.

Estimated time: 5-10 hours (depends on sewing skills)

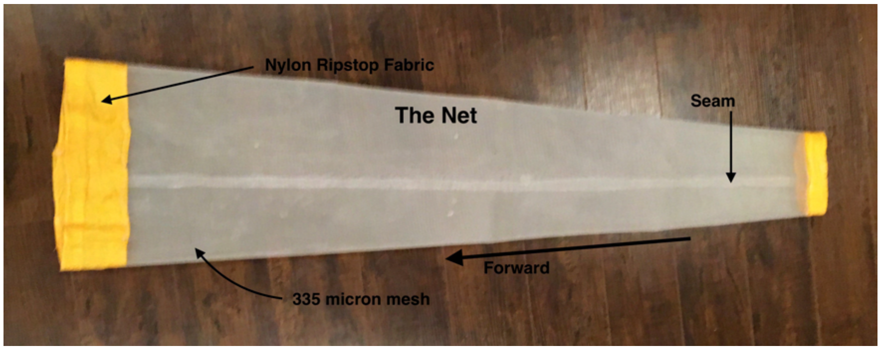


Figure 24: The completed net.

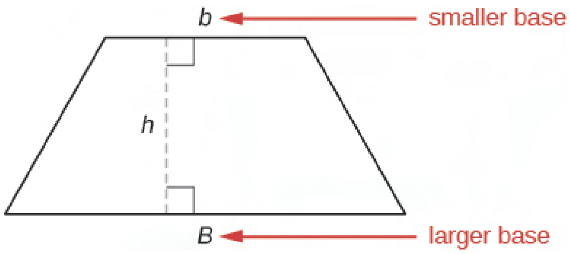
1. Start by laying out your big piece of mesh, making sure it is clean, and that there aren't any breaks or snags. In this section I have made a mini version of the net, to show the steps, since it is not easy to see the markings on a large piece and I am too short to take the pictures from above.

Figure 25: Step 1: Laying out the mesh for net-making.

2. The net's basic shape is a big trapezoid. We need to do some math to determine the height, large base (front of the net), and small base (top base and end of the net) of the trapezoid. Don't worry, it isn't hard math:

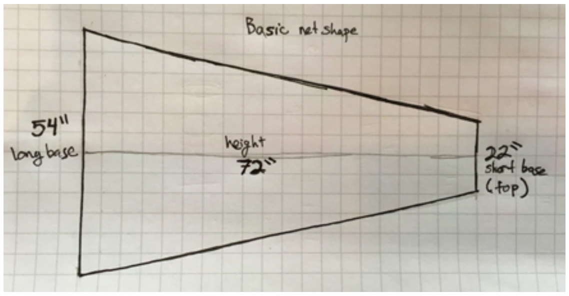
   - The height of the trapezoid is the length of the net. Trawling nets are typically fairly long, 1.5 meters minimum. If you are planning on trawling for a long time, or taking a big sample, you will want a longer net, up to 3 meters as on the Manta Trawl. If you are building a smaller trawl, 1.5 meters (about 60") is fine. We used 72" for the height our net.
   - The large base of the trapezoid should be 2-4" longer than the inside perimeter of the mouth of the trawl, between the frame and the molding. You will need at least 1" for a seam, and an extra couple of inches makes attaching the net a lot easier. A net diameter that is slightly too big is okay; slightly too small is not. The inside perimeter for our design is 51", so I measured the base of the trapezoid to be 54".
   - The top base of the trapezoid corresponds to the circumference of the cod end. For the 3"r piece of PVC pipe we used for the cod end, the circumference is about 18.8". Again, add 1" for a seam and a couple inches for insurance. I measured 22" for the top of my trapezoid.

   Remember to double-check your math! You may wish to do a quick sketch with your measurements so that you remember the layout, as in Figure 26b.



[28]

(a) A trapezoid with height and bases marked [28].



(b) The dimensions I used to make a large net.

Figure 26: Step 2: Make sure you know the proper height and base lengths when cutting your initial net shape.

3. Starting from one corner of the mesh, measure the base (54") along one edge, and mark the end with a permanent marker.
4. Along the other edge from the same corner, measure the height (72"), and mark the end. You should have something like Figure 27 at this point.

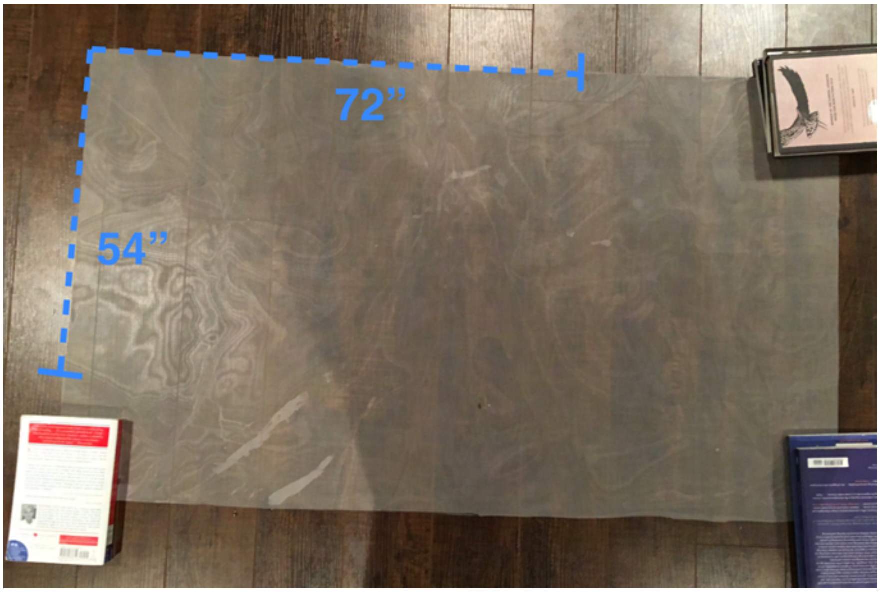


Figure 27: Step 3: Marking the height and long base of the net.

5. Find and mark the midpoint of this line (27" from the corner). This marks the centerline.
6. You may not have a meter stick to measure this length, and it is difficult to hold a measuring tape perfectly perpendicular. So find any straight edge you can, such as a baking sheet, or a pile of books and magazines. Then, starting from the base, line the spines up, along which the center line will be, as in Figure 28a.

(a) Using books to make a long straight edge.

(b) Use your earlier 72” mark to double-check your centerline.

Figure 28: Step 6: Marking the centerline on the top base.

The spines of the books should all line up with the midpoint of the bases. Mark the height along this line. Make sure it is in line with the 72” mark you made earlier. Make sure they are all flat against eachother and line up with the edge.

7. Measure the height (72”) along this line, and mark the intersection with a cross (this marks both the height, and the midpoint of the top base of the trapeziod). Now, from the 72” mark along the edge that you made in Step 4, measure half of the base (27”) towards your midpoint, and make sure that this point lines up with the cross you just made (Figure 28b). I would recommend against drawing the entire height line, as you will not need it and it will show when the net is done. Leave your straight edge/book line in place for now.

8. Using more books or another straight edge, from this cross, mark out the ends of the top base. Since this base is 22” long, the ends are 11” on either side of the cross. Step back and make sure that this is drawn parallel to the bottom edge, and perpendicular to the height line. Once you are sure, use a permanent marker and a straight edge to draw the entire top base (Figure 29).

Figure 29: Step 8: Marking out the short/top base of the trapezoid.

9. We will use a similar method for drawing the legs of the trapezoid. Starting from the corner used in Steps 3 and 4, use your eyeballs to estimate the correct angle from this corner to the corner of the top base, and begin laying out your straight edge between the two (Figure 30). Finding the correct angle will likely take some readjustment and good ol’ guess-and-check, but once you get it, use the edge and the marker to draw the length of the leg.

10. Repeat Step 9 for the other leg. Step back and admire your work.

Figure 30: Step 9: Using a straight edge to mark the edges of the net.

11. Cut out the trapezoid. Overlap the edges with an inch or so, and pin together as in Figure 31a. Don't use safety pins like I did in this picture, you will not be able to remove them after sewing the seam! Start pinning from the big end and work down; you may notice that the net does not want to form the angle that you want it to. To avoid the material folding up or crinkling, use lots of pins placed close together and be strict with the net. You may have a slight mismatch of the edges at the small end of the net, this is fine, just trim this end into a more circular shape. Don't remove more than necessary, it doesn't have to be perfect.

(a) Pinning the trapezoid into the net's final shape.

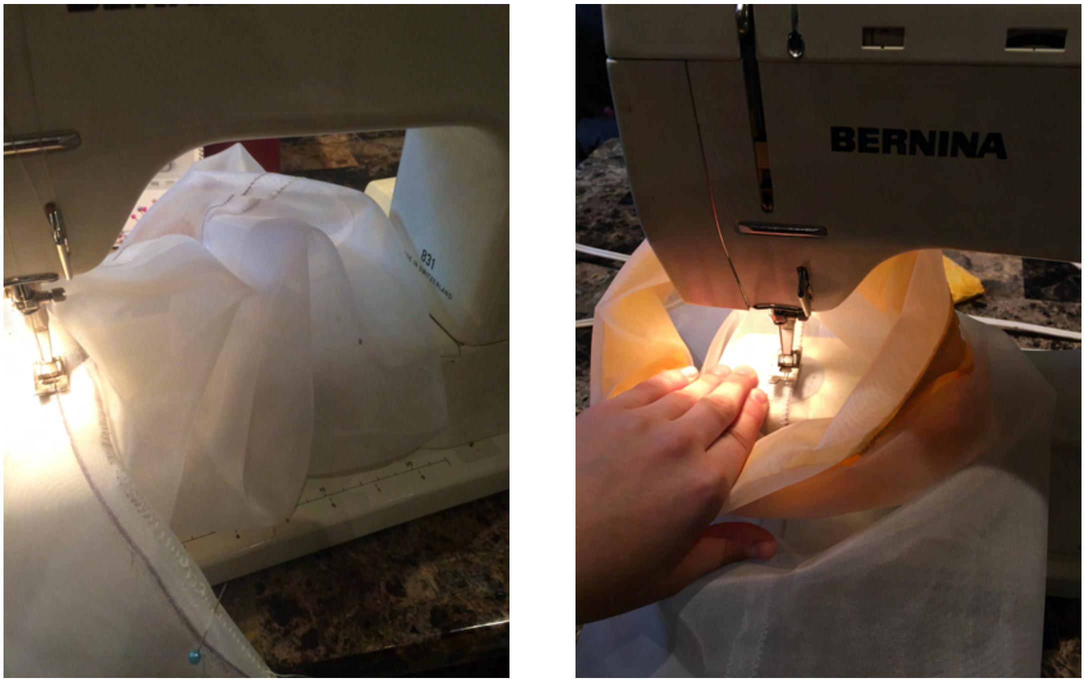
(b) A slight mismatch of the edges at the small end is expected.

Figure 31: Step 11: Pinning the mesh into the net shape.

12. Now we will sew the net. Start on one edge of the seam from the big end, and use a zig-zag stitch of about 3/8" width (no more than 1/4"!). Keep as close as to the edge as you can. Figure 33 shows the stitching and placement on the left and right edges of the seam. You will quickly notice that it is a difficult angle to work with, and there are two options as to how to orient your work.

    One way is to sew from the outside of the net (Figure 32a), in which case, if you start at the wide end, the piece will turn right and bunch up on the sewing arm as you move down the piece. This is not too bad intially, but as the diameter of the net shrinks you will not be able to continue pushing the net onto the sewing arm, and the excess material is rather annoying as you stop repeatedly to push it back.

    Another way is to sew from the inside (Figure 32b), and as you sew down the net, it bunches upwards, where you can grab it in your hands to prevent it from obstructing your view. This works better for a longer time, but you will only be able to sew in short bursts, stopping frequently to grab a handful of material every so you can see the needle. When the diameter gets too small for this method you can repeat the procedure starting from the small end.



(a) Sewing the seam from the outside. (b) Sewing the seam from the inside.

Figure 32: Step 12: Two methods of sewing the net's seam.

13. Repeat Step 12 for the other side of the seam.

Figure 33: Step 13: The 'double seam' method for sewing a creaseless net.

14. Now we will make nylon reinforcement for the openings of the net. For the large

opening, you will need a 5-6" thick strip of nylon all the way around, on both the inside and outside of the trawl. To start, cut a piece of nylon as long as the circumference of the large opening, plus an inch for a seam (54" again), and 12-14" wide (twice the desired thickness of the final strip, 10-12", plus two inches for a 1" hem on each side).

15. Take your nylon strip, wrap around and fold over the opening edge of the net, making sure you have enough fabric to go all the way around, and that there is an even flap on both the inside and outside of the opening (Figure 34).

Figure 34: Step 15: Pinning the top edge of the nylon reinforcement to the net's openings.

16. Pin the top edge down, and sew once all the way around with the same zig-zag stitch you used earlier, as in Figure 35.

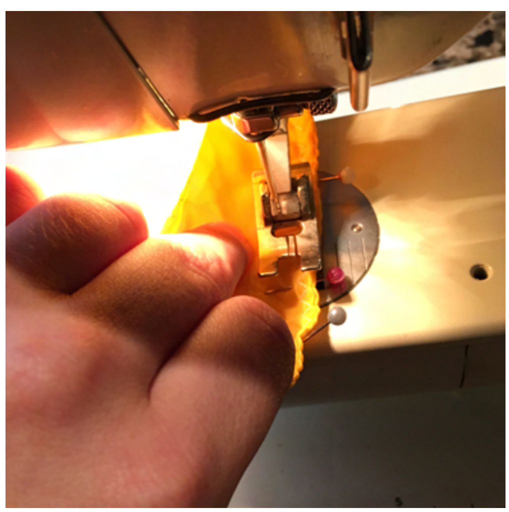


Figure 35: Step 16: Sewing the nylon reinforcement to the net opening.

17. Once the top edge is secure, remove the pins. Beginning with the inside flap, fold 1" of the loose edge under, and pin it down, creating a hem. repeat this all the way around

so there is one straight hem. Then, repeat with the outside edge, making sure that both hems line up. Figure 36 shows a close up of this double hem. This may take some practice to get right!

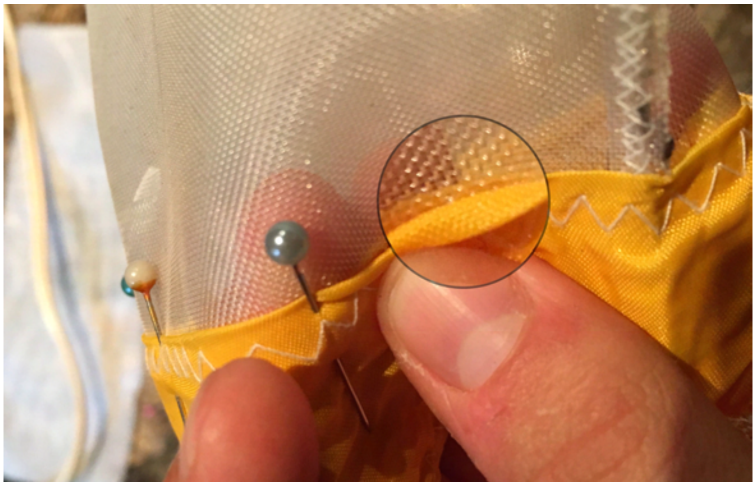


Figure 36: Step 17: A hem on the nylon is essentail to prevent fraying, contamination and loss of sample.

18. Sew this seam. Take your time, sewing through five layers of nylon and mesh can be slippery!

19. Now, repeat the process for the small opening of the net. Here you will only need the reinforcement to be 1-2" wide, so the nylon strip should be 4-6" wide, and 1" longer than the circumference of the small net opening, in our case 23" long total.

20. Congratulations! You have finished the net!

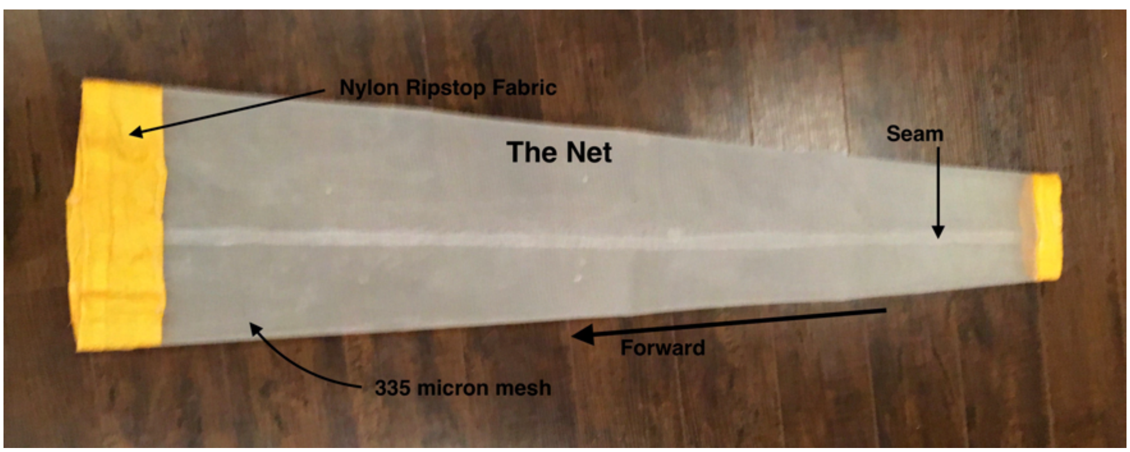


Figure 37: The completed net.

3.6 The Cod End

For this section, you will need:

- 5” of 3”r PVC pipe
- 3” or 4” hose clamp
- 333μm mesh
- Nylon fabric
- Sewing machine
- Sewing supplies (thread, scissors, pins)
- Measuring tape
- Nut Driver

Estimated time: 1-2 hours.

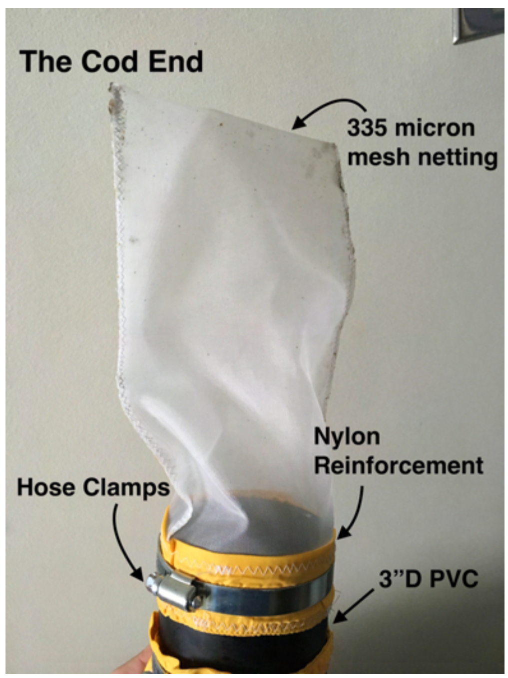


Figure 38: The completed cod end.

1. Saw off a 5” piece of 3”r PVC pipe. Sand the edges just enough to remove any snags.
2. Measure or calculate the circumference of the pipe. For a 3”r piece, the circumference should be 18.8”.

3. Cut a rectangular piece of mesh for the cod end. You will want the length of the finished cod end to be long enough for someone to invert it through the pipe while it is still attached, and be able to see the end come out of the other side. Including an inch or two for the mesh to be attached to the pipe on either side, anything more than 12” should be sufficient. If you intend to collect large samples by trawling for a long time, a bigger cod end will hold more and be easier to analyze. We chose 15”. The length of your rectangle of mesh should be twice this number, plus 2-4”, giving us 33”.

   The width of the rectangle should be half the circumference of the pipe (18.8”) + 1/2-1” to allow for sewing the seams. We used 10” for the width.

   If you are trawling nearshore or in lakes, you will need a longer cod end, because there will be more organic matter in the cod end and it may fill up. Both the PVC connection and cod end net can be lengthened to help with this. Ours is sized for the ocean.

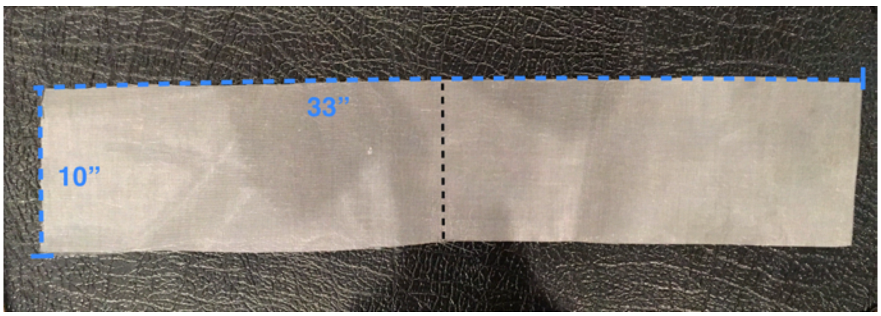


Figure 39: Step 3: A rectangular piece of mesh for the cod end.

4. The edges tend to fray quite a bit (Figure 40), which will quickly become annoying, and may leave fragments in the water. Very carefully, you can use a lighter to melt the edges just enough to be able to press them together. Be warned! The material can catch fire, so hold the flame at a distance, and be patient. You don’t want to burn a hole in the cod end and have to start over.

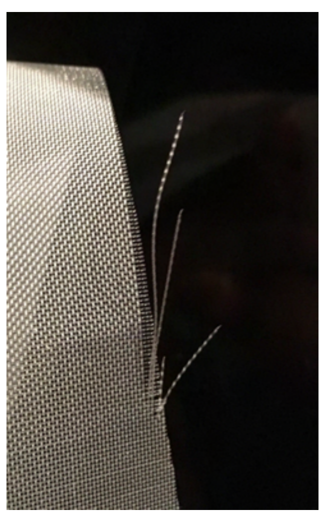


Figure 40: Step 4: Fraying edges can contaminate or lose samples.

5. Fold the rectangle in half along its length (along the dotted line in Figure 39). Pin the edges together.

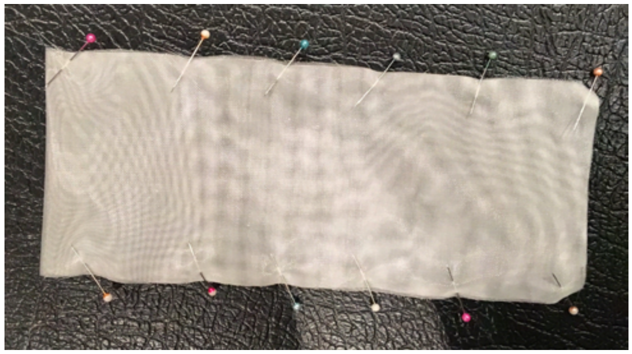


Figure 41: Step 5: Pin the cod end into shape to prepare for sewing.

6. Using a zig-zag stitch of about 1/8" width (no more than 1/4"!), and keeping as close as is safe to the edge, sew the edge of one side of the cod end, being careful to completely enclose the bottom corner. Then sew it again.
7. Repeat on the other side. Remove the pins. Check to make sure that the opening fits around the end of the PVC piece.
8. Cut a 3" nylon strip of the same width as the rectangle (10").
9. Take your nylon strip, wrap around and fold over the opening edge of the cod end, making sure you have enough fabric to go all the way around, and that there is an equal amount on both the inside and outside of the opening (Figure 34).
10. Pin the top edge down, and sew once all the way around with the same zig-zag stitch (Figure 35).
11. Once the top edge is secure, remove the pins,. Beginning with the inside flap, fold about 1/2" of the edge under, and pin it down, creating a hem with the end of the nylon between the flap and the mesh. repeat this all the way around so there is one straight hem. Then, repeat with the outside edge, making sure that both hems line up. See Figure 36. This may take some practice to get right!
12. Sew this seam. Take your time, sewing through 5 layers of nylon and mesh can be slippery!
13. When this part of the cod end is done, take the piece of PVC pipe, the net piece, a hose clamp and a nut driver, secure the net to the pipe together. Make sure it is tight, and try to get the attachment as close to the end of the pipe as possible to eliminate any major creases, which may affect sample collection by trapping microplastics.
14. Congratulations! You have finished the cod end.

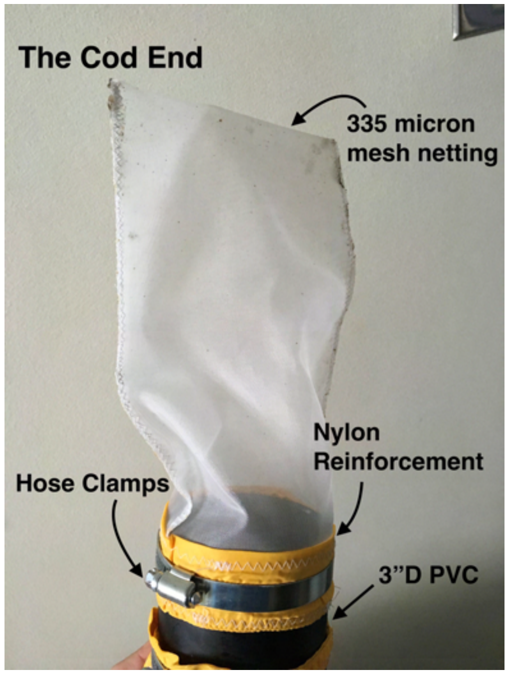


Figure 42: The completed cod end.

3.7 Putting it All Together

For this section, you will need:

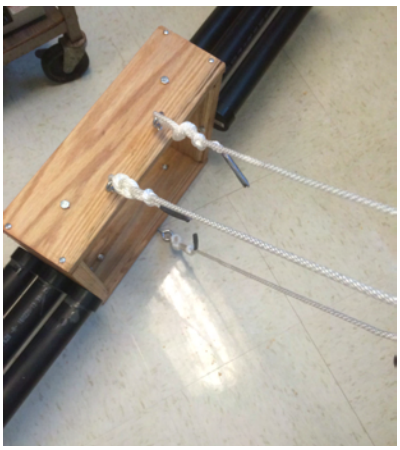
- 3" or 4" hose clamp
- Scissors
- Wrench
- Remaining rope
- Nut Driver

Estimated time: 1-2 hours.

1. The first and easiest step is to attach the cod end to the end of the net. Do this with another hose clamp as in Step 13 of the Cod End assembly.
2. To attach the net, first remove all the nuts from the bolts on the mouth of the trawl, but leave the bolts and wings in place. Then remove the molding.
3. Set the mouth standing upright. Starting with the bottom, line up the nylon reinforced opening of the net to where you want it to be when it is secured. make sure it is not pulled taught (a partner may help with this) when you use a sharpie to mark the location of the bolts. Use scissors to cut out small holes for the bolts.

4. Pull this side of the net onto the bolts. Place the bottom side molding back on, and use the wrench to re-tighten the nuts. Repeat this step for the *top* side next (make sure there is enough fabric to line all the sides of the interior comfortably, without stretching. Then repeat the left and right sides. Make sure everything is tightened down!

5. Add ropes for trawling. We like to have a set of primary ropes which we never remove from the trawl, these are about 5' long. Then when trawling on a boat we attach to a trawling arm with additional rope, depending on the boat's set up. This eliminates having to undo the knots multiple times.



(a) Note: the trawling eyes are not placed properly in this picture, they should be 2" from the left and right edges.

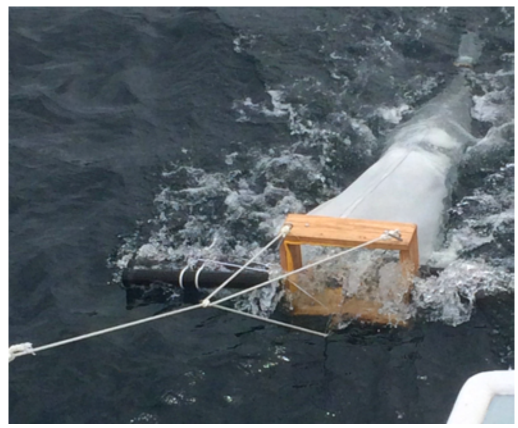


Figure 43: Step 5: Set-up of the trawling ropes.

We like to use two ropes; one rope attaches to the top-left eye at one end and the top-right eye at the other. The third rope attaches to the bottom eye, is tied to the middle of the upper rope, and extends onwards to be attached to the trawling ropes later. This setup is shown in Figure 43. For ataching these to the eyes we used a climber's knot, shown in Figure 44. The end of the longer bottom rope will be tied to a longer, adjustible traling rope on the boat with a Bowline Knot (Figure 45).

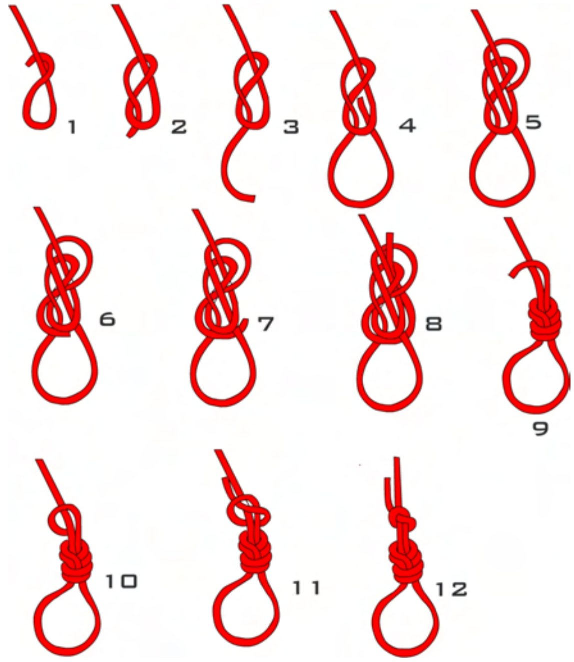


Figure 44: A Figure Eight Follow Through [16].

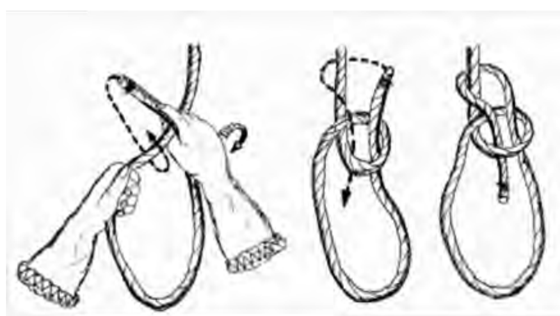


Figure 45: A Bowline Knot [17].

6. Congratulations! You have finished building LADI!

3.8 Alternatives and Modifications

LADI is designed to be adaptable and versatile. That is why she is build using easily found materials, and why this is being distributed under an open hardware license. As a reminder, under CERN OHL v. 1.2, you may modify and redistribute these plans, so long as the differences are noted, and proper attribution remains to me for the original documentation and to you for the additions or modifications. If you do make a change, I would love to hear about it, please feel free to contact me at my email: ccoyle@hmc.edu.

There are doubtless many ways to alter LADI that I have not thought of, however, here are some ideas:

1. Adding Color!

   Aesthetics are important! One thing you might want to think about is how you want your trawl to look. It might be nice to coordninate the colors in your trawl, especially the ropes, the nylon, the wings, and even the wood. Nylon and ropes come in many colors, and you may choose to spray paint the PVC (do this after the silicon is dry, but before adding ropes, unless you want to paint the ropes as well). There are many different colors of wood stain/sealant available, or you may even paint the wood as well (after sealing it). Come up with a cool design? Let us know!

   Note that if you are intending to do any chemical analysis of samples collected, this may affect the results and a control sample should be collected.

2. Just Enough Rope

   We did use LADI for a day of trawling at 3.5 knots successfully without rope strengthening the wings, so it is possible to use them without the ropes. However I cannot comment on how long thi arrangement will last or how it affects performance in rougher waters or higher speeds, so I still recommend having the ropes. At high speeds the wings will dip below the surface of the water more often, and the stresses on them will be even more significant. If you do choose to go without the rope reinforcement, I would recommend keeping trawling speeds lower.

3. Scaling

   LADI is scalable

   The smallest possible size is limited by how LADI behaves in choppy water. To get an accurate sample, you will want the surface of the water to *always* be within the mouth of the trawl. The shorter the mouth is, the less likely this is. I have not tested a smaller LADI on the water, but I would recommend not going below 10” height. Width is a little more variable, so long as you have enough room to work inside the mouth.

   On a smaller LADI, you may choose to use shorter wings as well. Oak is less dense than water, so the mouth will always float, but the wings help keep LADI upright, keep the water at the desired level at about the halfway mark in the mouth, get her to ‘skip’ over choppy waves, and keep her from dipping down at fast speeds. So I would recommend keeping the wings at least 12” long.

   The net can be shortened as well, but keep in mind that this will reduce overall possible trawling time. 5’ long is a good minimum for the total trawl (mough + net + cod end).

   To make LADI bigger, upper limits have more to do with how hard it is to carry and transport her. She is not designed to be taken apart for transport, but it should be possible with care; you will need to unscrew the wings and take care that the bolts are not accidentally lost inside the wings (surprisingly easy to do!). Keep in mind that a bigger LADI will also increase the drag on your trawling vessel.

You may need to add an extra PVC pontoon to the wings if you make the mouth deeper. Or if she is big enough, you may increase the diameter of the PVC used for the wings.

4. Using a Bongo net

   It is a bit simpler to use the Bongo net than to make your own, but here are a few tips:

   - Double and triple-check that the net diameter you purchase is big enough, or bigger than, the mouth size you intend to build. It is easier to use a slightly-too-big net than a too-small net.
   - Attach the net to the trawl in the same general way.
   - Give yourself a few extra weeks for delivery.
   - Have an alternate plan for making a cod end.

5. Using a single seam

   If sewing the double seam outlined in Section 3.5 is too difficult, you may choose to use a simpler seam such as in Figure 46, emulating the Manta Trawl's own net:

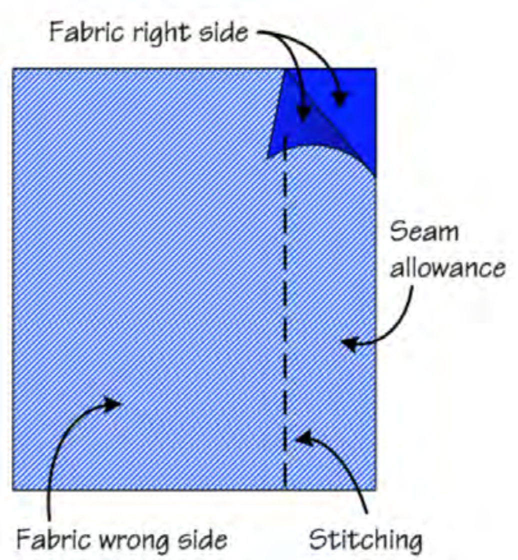


Figure 46: A simple seam [30].

4 Protocols for Deployment and Sample Collection

By Melissa Novaceski

Figure 47: A makeshift trawling arm.

Before starting your trip:

1. Download a location tracker app that uses GPS, and doesn't require cell service (we used MapMyRun by Under Armor, which is free on iOS and Android).

2. Check that the boat you are using has an arm for trawling which can withstand the drag of LADI, or figure out how to McGiver your own (we have had success tying flagpoles and planks of wood to stick out of the side of the boat, see Figure 47).

3. Check that the boat also has a water pump on board, or bring additional materials for cleaming thae samples from the net (listed below).

4. Check the weather and plan your trip, dress, and departure time accordingly.

5. From previous visits or a brief visual inspection, talking with local fishermen or others, Internet research, consideration of recent wind patterns or a brief visual inspection, estimate how much debris will be on the surface of the water. This will help you determine how many and how big the samples will be. Accordingly, plan how long you want to trawl, how many trawls you will do, and how many sample bottles you need.

   The more trawls you do, the more accurate your results will be. If you just want to see what kinds of plastics are in an area or if there are any at all (a qualitative analysis), shorter or fewer trawls are fine. If you want to model how many plastics are in an area, you need to do enough trawls for lengths of time that correspond to the body of water you are sampling–over the oopen ocean, in a gyre for example you can trawl for over an hour and do 20+ trawls. In a Bay, trawl times might be 30 minutes and you would need 10.

6. Make sure you have these materials:

(a) The trawl herself
(b) Cod End and extra cod end, if you have one
(c) 3x 3" or 4" hose clamps for the cod end (or whatever size you used)
(d) Extra hose clamps if possible
(e) Nut driver
(f) 1/4" wrench
(g) Extra rope for trawling
(h) Glass or plastic sample jars (the number depends on how many trawls you plan to do, how much 'junk' is on the surface of the water, and how long you plan to trawl. Bring more than you think you will need!)
(i) 335 μm sieve
(j) 2x permanemt marker
(k) Log book for data (a waterproof notebook will help)
(l) Duct Tape
(m) Rubber bands
(n) Drinking water and food
(o) If your vessel doesn't have a pump, bring a bucket or two (either pre-filled with fresh water or to use for filling with filtered water)
(p) a few bottles which can be used for squirting water out of the top

After reaching your desired trawl location:

1. Set up the arm and trawling ropes so LADI will be on the side of the boat, not close enough to be bumped and not in the wake (which causes downwelling of plastics, and will ruin your sample).
2. Before each trawl, make sure there are two or three hose clamps attaching the net and the cod end and that they are as tight as you can make them!
3. Do a short 'practice run', no data recording or sampling necessary, to flush out any particles in the net, and to make sure LADI is in the location you want at speed.
4. Adjust the ropes or arm if necessary. Wash out the cod end.
5. Record latitude and longitude just before deployment.
6. Start your tracker app just before deployment
7. Lower the trawl into the water on the side of the boat, making sure to drop it upright with the net trailing behind and avoiding the wake.
8. Pull the trawl (try to maintain a consistent speed) for your predtermined length of time, or if you notice the cod end is filling up quickly, try to end the trial before the net gets overfilled.

9. When you have finished your trawl, stop the tracker app, stop the boat, and pull the trawl out of the water.
10. Collect the sample (Protocol in Section 5), and thoroughly wash out the entire net and cod end.
11. Trawl in both or multiple directions to avoid direction bias, either within or between trawls.

4.1 Troubleshooting

If the sampling area contains a large amount of debris on the surface trawl for a shorter period of time (10 minutes or fewer). Aim to have the water level half way between the top and bottom of the mouth of the trawl, this can be adjusted by adding weights such as rocks or fishing line weight to make it sit lower in the water. The mouth of the trawl should be perpendicular to the surface of the water, this can be done by adjusting the length of the chin strap of the trawl to angle it forwards or backwards.

If the trawl dumps, spills, or is caught in the wake, the sample can only be used for qaulitative data rather than for statistical modeling of the quantity of plastics in the area.

5 Protocol for Sample Analysis

By Emilly Wells

5.1 Sample transfer in the field

Equipment

- LADI Trawl with collected sample
- Nutdriver to unscrew hose clamp(s)
- Spray bottles or hose (with uncontaminated water)
- 335 micron mesh sieves (Figure 48)
- Permanent marker for labelling
- Large sample containers (500 mL); glass or plastic for holding the sample

Figure 48: A 335 metal Sieve, from Neobits [29]

Transfer sample from trawl to sample container(s).

1. Using running water from a source such as a hose or spraying bottle, rinse the sample from the trawl net into the cod end, starting near the opening and working towards the end.
2. If the sample fits into the cod end, remove the posterior hose clamp and (a) invert net over a sieve and thoroughly rinse from the top to the bottom with uncontaminated water, thereby placing the sample in the sieve, (b) set the cod end aside for later processing, or (c) trawl for less time for future trawls to avoid the cod end overfilling.

   If the sample is large and does not fit the into cod end, (a) remove the hose clamp from anterior end of the PVC and rinse the sample from the upper netting into the sieve. Process the sample as per (iii) and (iv). Remove the hose clamp from the posterior end of the PVC and rinse the sample from both the PVC and the cod end into the sieve. Process as per steps (iii) and (iv).

   NOTE: Rinse the seams of the netting thoroughly, as small particles - including plastics - tend to accumulate there. To hold the cod end open for easier rinsing, have one person rinse while another pushes the side seams towards each other, thereby creating a cylinder-like shape. Rinse from top to bottom. Ensure that the mouth of the cod end does not touch the sieve while transferring the sample and rinse anything that contacts the sample using uncontaminated water over the sample container.

3. If feasible, remove large organic materials from the sample. Pick up the organic with your hand, rinse it thoroughly over the sieve, visually inspect it to ensure that no plastic debris remains adhered, discard it, and then rinse your hand over the sieve, ensuring no plastic debris remains on your hand.

   NOTE: Mind the water pressure when working with the sample in the sieve, as high blasts of water may splatter the sample and splash it from the sieve.

4. For samples that contain a large number of large organic materials, use your hands to transfer the sample directly into labelled containers and then rinse your hand over the container with uncontaminated water. For the remaining sample, and for smaller samples, spray the sample into a single point on the edge of the sieve. Spraying may be performed from the front or through the back of the sieve. Transfer the sample into a labelled container by placing the container near the rim of the sieve and directing the sample into it with your finger. Thoroughly rinse your finger over the container with uncontaminated water. Cap the containers and set aside for later processing.

   NOTE: The container label indicates: trawl run (example: LADI4); of more than one container, indicate the container identifier (example: LADI4.A); and the location.

5. Add a few mL of hydrogen peroxide to sample jars.

6. Repeat steps 1-4 for each trawl run.

5.2 Laboratory work

Equipment

- Lab coat and hair ties for long hair
- Petri dishes (amount depends on the number of samples)
- 335 micron mesh sieves
- Dissecting microscope
- Tweezers
- Fine point permanent marker for labelling
- Sink or source of running water
- Double sided tape
- Optional: masking tape for labelling

- Contamination: Samples can become contaminated by particles (micro fibers) present in the air, on the clothes of workers, in poorly cleaned instruments, or by improperly sealed samples. Control samples should always be used to confirm that there is no procedural sample contamination. A control ensures that the fibers found in our study are not a result of contamination during processing. It will also enable us to characterize plastic contamination in the laboratory (instructions for how to create a control below). To reduce and account for contamination:
  - Wear natural fibers like cotton or wool instead of petrochemical fibers like fleece or nylon
  - Wear a lab coat or cotton overcoat and tie hair back
  - Immediately before sampling, rinse your hands and wipe down any tools
  - Work efficiently and cover the petri dishes and sample bottles whenever they are not in use
  - Tie back long hair
  - Collect a control sample during sample collection processing (Step 1 below).

Store the samples: You may top up sample jars with hydrogen peroxide and store samples in fridge until analysis. This will alleviate a strong smell as organic matter decays.

Processing sample to remove plastics:

1. To create a control that captures background microfibre and other plastic particle contaminate, put double sided tape in the bottom of a petri dish and leave the dish open next to the work area. Record the date the control was started on the dish. Everyone working on the samples should dust their clothes off into the dish.
2. If samples are large and contain many organic materials, dump the content of the bottle into the 335 micron sieve and remove any remaining large organic materials by rinsing and disposing them (as discussed in (Stage 1-iii)). Depending on the size of the sample, this may take a long time.
3. Place an opened petri dish labelled ‘Control’ in the area where you are analyzing the samples.
4. Place an amount of sample in a petri dish so that it forms a thin layer in the dish: enough so that the contents do not float.
5. Systematically analyze the dish under a dissecting microscope. Move the dish back and forth in the field-of-view and use tweezers to probe through the dish contents. Remove any suspected plastics and place them on a separate petri dish (see below Plastic Analysis Guide).

   Tips:

- If the probable plastics are sticking to the tweezers, place a drop of water on the probable plastics dish. The material better adheres to the water than the plastic dish.
- Placing the probable plastics dish on top of a blank piece of paper will make the contents visible.
- You may wish to organize the probable plastics according to suspected type for ease of processing (pellet, film, thread, foam, fragment, microbead, other; see Plastic Analysis Guide).
- Once a first viewer has analyzed the entire dish, have a second viewer repeat the analysis to ensure that all plastics have been detected.

6. Label the dish cover with trawl run identifier (example: LADI4.A), either directly with marker or on a piece of masking tape. Replace the cover on the petri dish and set the samples to dry overnight (until samples are dry) along with the control dish.

Validation and Quantification of Plastics Equipment

- Microsoft Excel
- Digital calipers
- Compound microscope
- Scale
- Small jar

1. An example spreadsheet that we used for analyzing data from Holyrood is included in Appendix C.
2. Assess whether the probable plastics are plastics (see Plastic Analysis Guide).
3. Separately quantify each plastic and log into an excel file: Trawl ID: Corresponds with the trawl run (example: LADI4) Plastic ID: The identifier for an individual plastic (example: LADI4.1 is the first plastic quantified from trawl run LADI4; LADI4.2 is the second plastic; etc.)
4. Plastic type: pellet, sheet, thread, foam, fragment, microbead, or other (see Plastic Analysis Guide) Plastic color: The predominant color of the plastic. Can be white, clear, red, orange, blue, black, gray, brown, green, pink, tan, or yellow
5. Plastic size: Use caliper for all size measurements. If it is a sphere, measure the diameter. If it is cylindrical, measure the diameter and the height. If threads are found in a bundle or are coiled, do not unravel them. Keep them as a bundle or in coiled shape and count as one item, measuring the dimensions as best you can. If the measurement is too small to be detected by the caliper, record that it is less than the smallest measurement the calipers record.

(a) Plastic length: the longest measurement

(b) Plastic height: the middle measurement

(c) Plastic width: the smallest measurement

(d) Plastic weight: Weigh the plastic on a scale. If no weight is detected, record that it is less than the smallest measurement the scale records.

(e) Plastic erosion: General comments on the weathering of the plastic (jagged edges, faded, angular; see Plastic Analysis Guide for more terminology)

(f) Notes: General comments on the process and shape of plastic.

NOTE: If a plastic is lost during the quantification procedure, note it in the Notes column and place and X in the cells with missing data (not a 0, as this would conflict with numerical data).

6. Place plastics from the same trawl run in a small jar labelled with the trawl ID (i.e. LADI4).

5.3 Plastic Analysis Guide

Careful visual sorting is necessary to separate plastics from other materials, such as organic debris (shell fragments, animals parts, dried algae, or seagrasses, etc.) and other items (metal paint coatings, tar, glass, etc.). It is recommended that more than one individual verify the probable plastics.

Pieces of microplastics <5mm can be generally identified by the following criteria:

- Lack of cellular detail and organic structures (i.e. venation)
- Color: plastics may be distinctly colored, such as: white, clear, red, orange, blue, black, gray, brown, green, pink, tan, or yellow
- Weathering: scratches and edge formation can help identify plastics
- Reflectivity
- Strength and brittleness: plastics are hard, flexible, or squishy (like foam). Organics tend to stretch when wet and break apart when dry
- Fibres are generally equally thick throughout their length

Types of Plastic:

1. Pellets: These are small, often cylindrically-shaped granules about 4mm diameter, but also disc and rectangular shapes occur. Various names are used, such as pellets, beads or nurdles.

2. Sheet-like user plastics (film), as in plastic bags, foils etc., usually broken up in smaller pieces;

3. Thread-like user plastics (thread) as in (remains of) ropes, nets, nylon line, packaging straps etc.
4. Foamed user plastics (foam), as in foamed polystyrene cups, packaging or aquaculture, or foamed polyurethane in matrasses or construction foams;
5. Small pieces (fragment) of more or less hard plastic items are broken off from a huge number of sources (bottles, boxes, toys, tools, equipment housing, toothbrushes, lighters, etc);
6. Microbeads are used as an exfoliant in personal care products like face wash and toothpaste. They are often brightly coloured, very small, and perfectly round.
7. Microfibers are from synthetic clothing like fleece or nylon
8. Other, such as cigarette filters, rubber, elastics etc., so items that are plastic-like or do not fit into a clear category.

Appendix B contains a document with examples of each type of plastic described here.

6 Validation

To determine that LADI collects representative and useful samples, we tested her in three ways. First, at the flume tank at the Marine Institute, where we recorded the drag she produced, used dye packs to visualize waterflow around the mouth, and visually compared performance at different speeds. These tests were repeated on the Manta Trawl from 5 Gyres (Figure 3) as the standards we intended to acheive. Second, we performed a series of trawls at Petty Harbor with LADI and the Manta Trawl simultaeneously, in order to compare the samples they both collected and determine if they produce similar results. Finally, we used LADI alone at another location, Holyrood, and did a full set of trawling and data analysis both to exemplify how to do a complete surface plastics study with LADI and to examine her performance throughout a long trawling session.

6.1 Flume Tank Testing

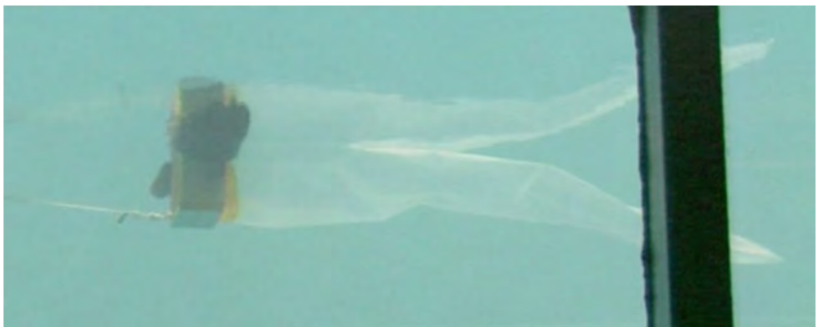
On July 13th the team was invited to use the 1.7 million liter flume tank at the Fisheries and Marine Institute of Memorial University of Newfoundland, thanks to the kindness of Dr. Paul Winger. We used our day to conduct several tests on our trawls, including:

- Visual inspection of trawl performace at 0.5, 1.0, and 2.25 knots (the maximum speed of the flume tank)
- Drag measurements at 0.5, 1.0, and 2.25 knots
- Dye tests at 2.25 knots and 1.0 knots

For this day of testing, we opened viewing of the flume tank to the public. We were able to talk about our work with others in the MUN community, the local media, and even guided a pair of young girls in building their own Baby Legs, a smaller DIY trawl we were also testing that day, developed by Max Liboiron [18].

Speed Tests

(a) Front view.



(b) Side view.

Figure 49: LADI at 0.5 knots.

(a) Front view

(b) Side view

Figure 50: Manta Trawl at 0.5 knots.

Figures 49 and 50 show how LADI and the Manta Trawl sit in the water at 0.5 knots, or about 0.6 mph. At this speed, we noticed that both trawls are steady, not listing, twisting, or wavering, and that the surface of the water remains in the ideal location in the middle of the mouth at all times. Both trawls naturally orient themselves in the correct direction once thrown in the water, and remain upright throughout.

(a) Front view

(b) Side view

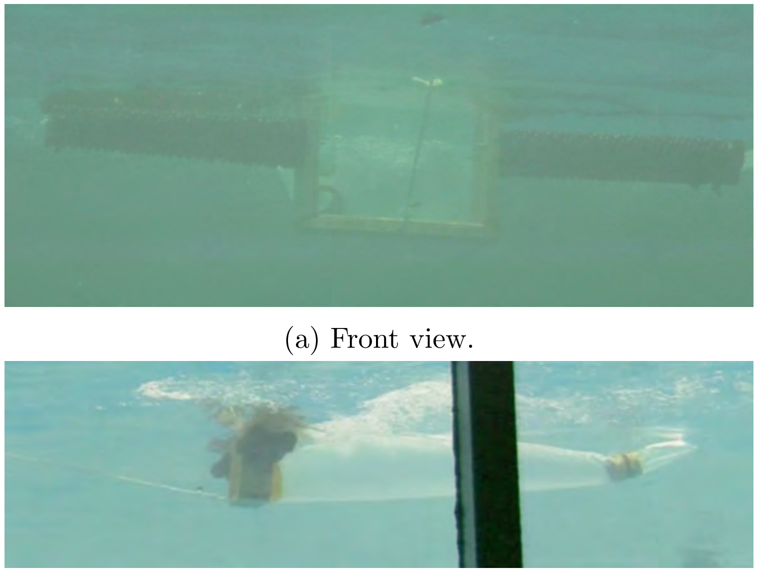
Figure 51: LADI at 1.0 knots.

(a) Front view

(b) Side view

Figure 52: Manta Trawl at 1.0 knots

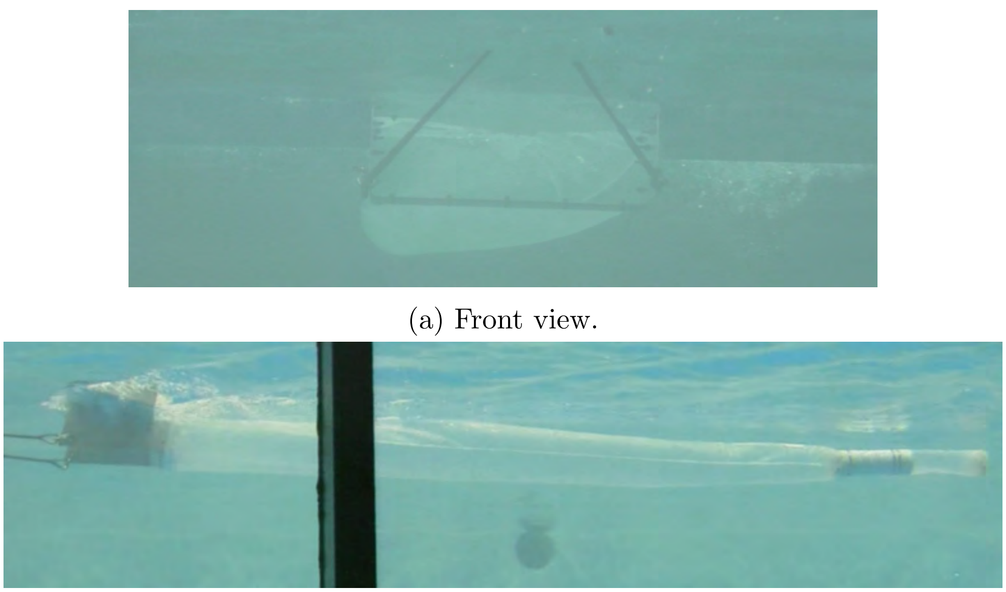
Figures 51 and 52 show how LADI and the Manta Trawl sit in the water at 1 knot, or about 1.15 mph. We now notice that the Manta Trawl's mouth naturally angles upwards a little more. LADI does not tilt, but is sitting lower in the water, due to increased drag on the net. Both trawls are still steady and the water's surface remains in a good location.



(a) Front view.

(b) Side view.

Figure 53: LADI at 2.25 knots.



(a) Front view.

(b) Side view.

Figure 54: Manta Trawl at 2.25 knots.

Figures 53 and 54 show how LADI and the Manta Trawl sit in the water at 2.25 knots, or about 2.6 mph. As you can see in the images, Manta's tilt is now more pronounced. We also can see a similar tilt in LADI. At this and higher speeds, LADI's wings produce a lift force, counteracting an increasing downwards force from an increasing drag on the net, keeping LADI's mouth upright and at the surface.

Drag Measurements

Table 3 shows the drag measurements for LADI and the Manta Trawl at three speeds. While LADI consistently produces less drag, both should be usable even by small motorized boats at medium speeds. For example, we succesfully pulled both LADI and the Manta Trawl at 5 knots at Petty Harbor (Section 6.2).

Drag Measurements		
Speed	**LADI**	**MT**
0.5 kts	0.315 kgf	0.416 kgf
1.0 kts	1.398 kgf	1.976 kgf
2.25 kts	9.780 kgf	10.705 kgf

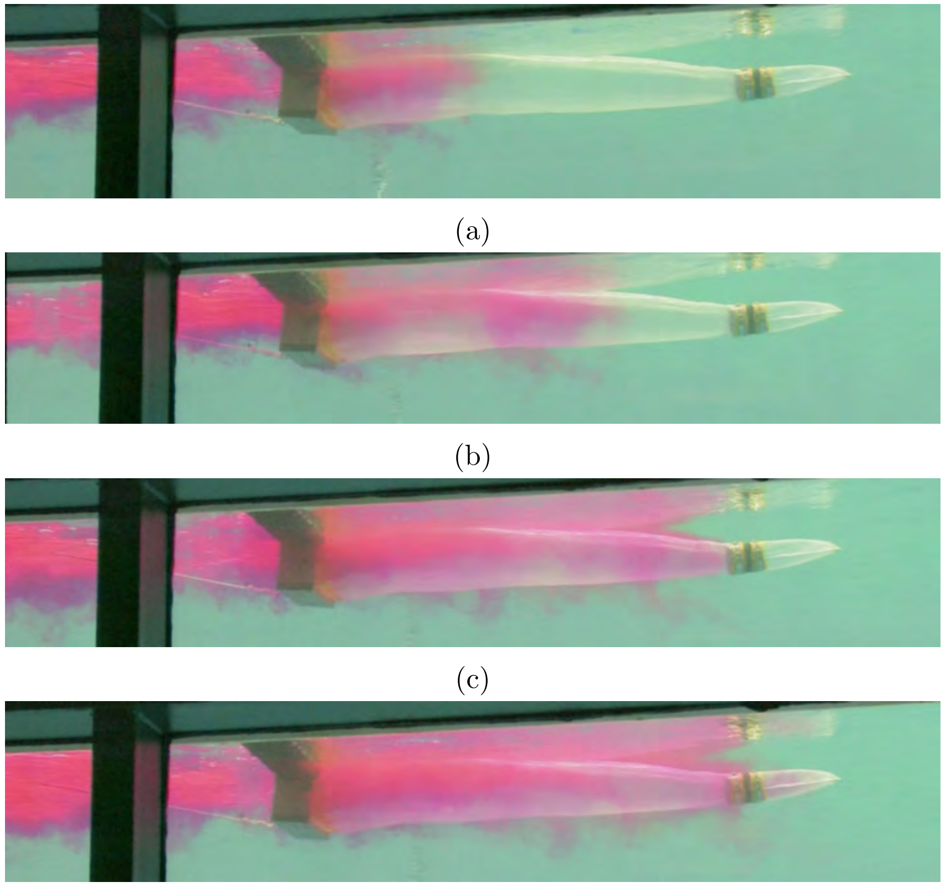
Table 3: Drag produced by LADI and the Manta Trawl (MT) in kilograms of force (kgf), at different speeds in knots (kts)

Dye Tests

In order to examine the way water moves through the mouth of the trawl, we used dye to visualize the trawling process. We were specifically looking for any backflow (water which enters the mouth but is pushed out again) or misdirected flow (surface water which is in the path of the mouth, but is deflected and does not go through it). We used green dye pelletes glued to the mouth of the trawls before dropping them into the tank to see if there were any problems at the beginning of deployment. We also poured liquid red dye ahead of the trawl after it was already in the tank to examine normal usage during the middle of a trawl. We performed these two tests on both the Manta Trawl and LADI at 1 knot and 2.25 knots.

It is difficult, in a two-dimensional format, to show the success of the dye tests, however Figure 55 shows a progression of one red dye test on LADI. You can follow the clouds of dye to see that they progress through the net in a redictable manner, and that there is no noticable wake or turbulence near the mouth of the trawl.

We did not detect any significant difference between LADI and the Manta Trawl's performances in these tests, and did not see any backflow or misdirected flow in either.



(a) (b) (c) (d)

Figure 55: Dye test on LADI at 1 knot.

Conclusions

Several important observations prove these tests successful. By observing the trawls at different speeds we were able to determine that both LADI and the Manta Trawl respond to different speeds appropriately and correct their position so that the surface layer of the water is near the middle of the mouth at all times, an essentail design component.

The drag measurements revealed that LADI is indeed a bit easier to use on a smaller vessel, being a smaller trawl in general and having a shorter net. However given the Manta Trawl's similar drag measurements, LADI could easily be scaled up and still be usable ona small vessel.

The dye tests confirmed that both trawls are hydrodynamic enough not to cause a disturbance which could hinder sample collection or bias a sample.

Overall, flume tank testing confirmed that LADI is operationally competitive with the Mant Trawl, i.e., they both satisfactorily fulfill all the functions of a surface trawl.

6.2 Validation Against Manta Trawl

On July 31st, 2016, the team (at this time including Coco Coyle, Emily Wells, Max Liboiron, and boat captain Pat Wells) took LADI and the Manta Trawl to Petty Harbor, Newfoundland. With a strong easterly wind, a great amount of floating debis (organic and not) had blown into the area. While we intended to complete 5 20-minutes trawls with both the Manta Trawl and LADI deployed simultaneously, we soon realized that the cod ends on both trawls were competely filled with debris in under 10 minutes. Quickly we ran out of sample jars and had to improvize by using empty freshwater buckets to hold the entire cod end, until we could return to the lab to complete the protocol by processing the samples through the 335 micron sieve and placing them in sample jars. To give you an idea of how overwhelmed with the size of the samples we were, we anticipated using 10 on-site, brought 12 for insurance, and ended up needing 24 total! Thus our trawling was limited to two for both LADI and MT.

Following the protocols laid out in Sections 4 and 5, two trawls with LADI and the Manta Trawl deployed simultaneously.

As of August 23rd, 2016, the data are still be processed from these samples. This report will be updated as soon as this is completed. Expected completion is Winter 2016/2017.

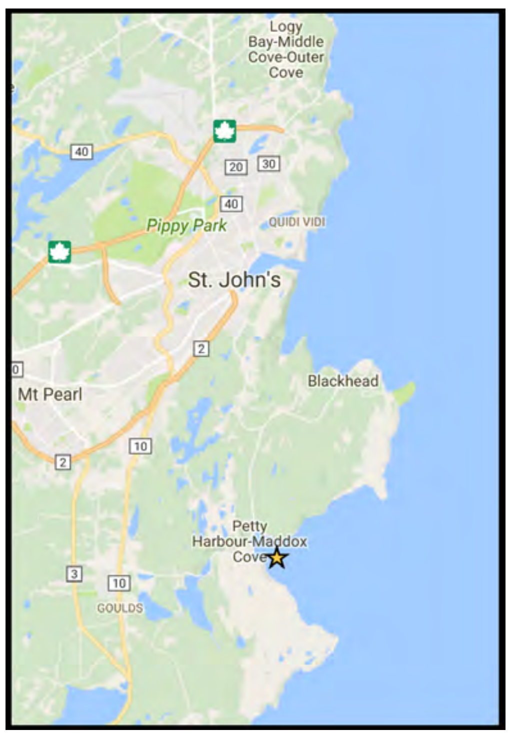


Figure 56: Location of trawling at Petty Harbor. Image taken from Google Maps.

6.3 Case Report: Holyrood

On June 24th, the team boarded Costal Connections, in Holyrood (Figure 57) [19].Using the deployment protocol described in Section 4, we completed many trawls that day, testing not only LADI but a couple of other trawls in development as well. We ended up with five valid trawls of LADI, the details of which are shown in Table 4. The start locations of each trawl are also marked on Figure 57. Note that trawls 1, 2, and 3 are in a slightly different location than trawls 4, 5, and 6.

Figure 57: Location of trawling at Holyrood. Image taken from Google Maps.

Holyrood trawling data				
Trawl #	Time (min)	Distance (km)	# plastics Found	Plastic density (#/m^{2})
1	N/A	N/A	N/A	N/A
2	23:59	1.79	3	0.0053
3	21:07	2.08	7	0.0107
4	12:11	2.17	19	0.0278
5	22:21	1.97	3	0.0048
6	20:54	1.85	11	0.0188
		TOTAL:	43	0.0135

Table 4: Holyrood trawling data.

Following the sample analysis protocol as in Section5, we found 43 plastics total. The complete raw data (including a catologue of each individual plastic found) are included in Appendix C. Because we had a mechanical flow meter (from General Oceanics) attached to the mouth of LADI, we used its record of distance travelled, considering it to be more accurate than the GPS-based phone app since GPS is limited to an accuracy of ±10 feet [20]. Once you have found the number of plastics from each trawl, you can calculate the number of plastics per surface area travelled. Because microplastics float in the first few centimeters of the water's surface, plastic counts are reported per surface area instead of volume. The calculation is not difficult:

$$\frac{\#\text{of plastics found}}{(\text{distance travelled}) * (\text{mouth width})} \tag{1}$$

Where the distance travelled and mouth width are both in meters. Then you can take an average of this number for each trawl for a more accurate result, or if you have more trawls to compare, perform a more complete statistical analysis. With this method, we found an average of 0.01348 plastics $/m^2$ in the Holyrood area.

Thanks to statistician Louis Charron of Memorial University of Newfoundland, who performed a brief statistical analysis of our work. He confirmed our calcuations and found that the area is continuous, meaning there is no significant difference in plastic content between the first trawling location (1, 2, and 3) and the second trawling location (4, 5, and 6). This report is included in full in Appendix D.

The LADI trawl is able to collect samples reliably and consistently, and the data from samples is not statistically random or noisy, but consistent between samples, indicating internal validity through consistency.

7 Acknowledgements

The Hixon Center for Sustainable Design at Harvey Mudd College and the Rasmussen Fund for supplying funding this project.

MEOPAR, MUN interdisciplinary grant, and SSHRC IDG all providde funding to CLEAR, and funded some of the materials for this project.

Jan Negrijin and the Hillary Wainwright of Costal Connections, who donated a day of trawling for our testing and assisted us in our work that day.

The operators of the flume tank at the Marine Institute, who gave us a day of testing at the flume tank and helped us conduct our tests and to take videos and pictures.

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Pat Wells, who also gave us a day's use of his boat for testing and his garage for construction.

Christy Spackman, who not only edited this entire document, but was from the start and continues to be an adviosor to this project and to me, and who wisely connected me to Max in the first place.

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Last but not least, my friends who listened to me talk endlessly about this project or reviewed parts of my writing, and those who challenged me with questions and ideas for improving my design.

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Appendices

A Manta Trawl Designs

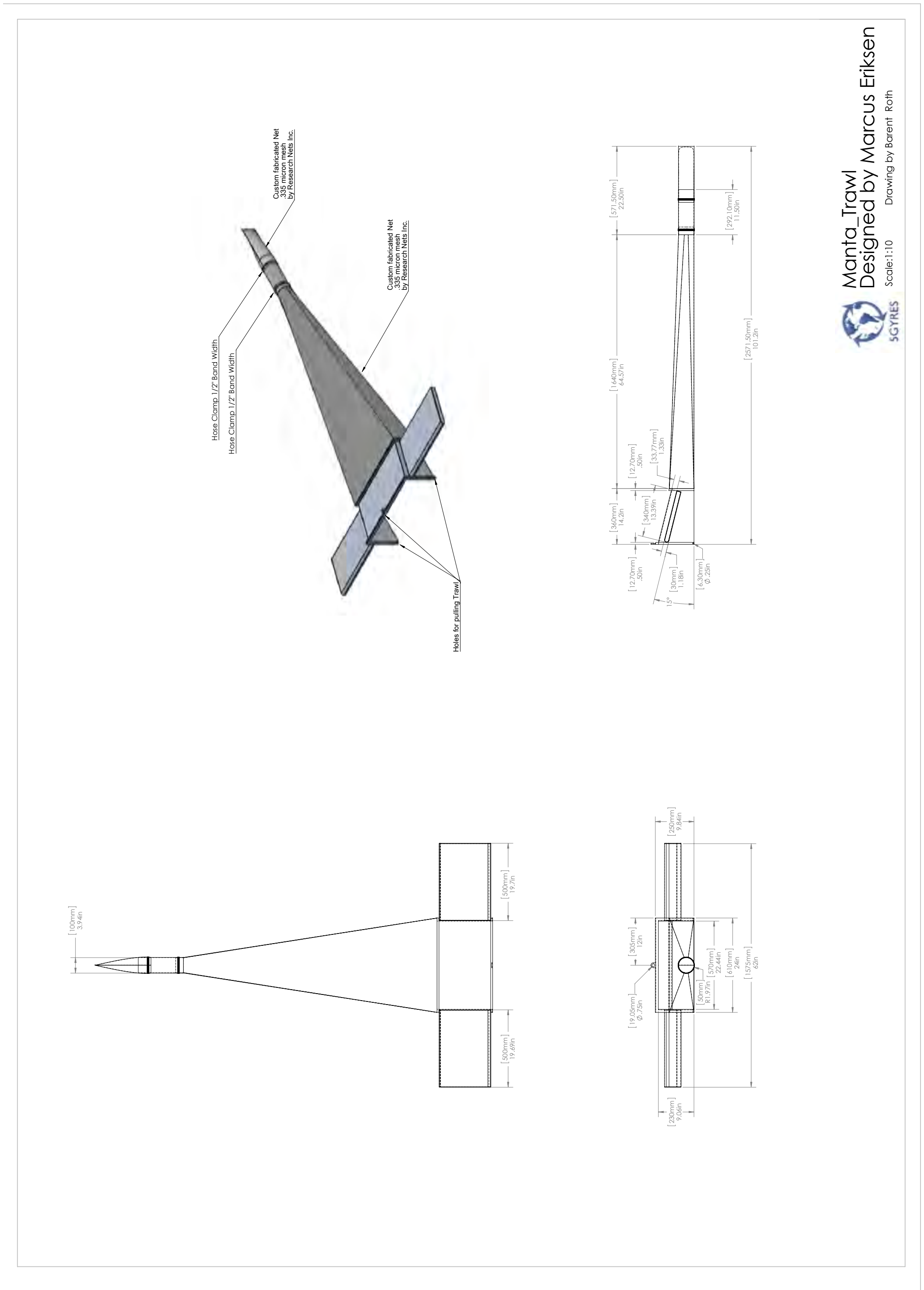
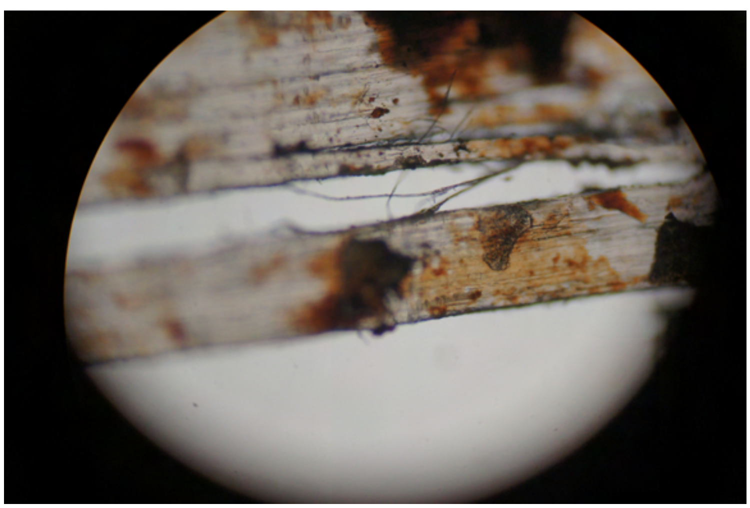


Figure 58: Manta Trawl Design credit to Marcus Eriksen, Drawing credit to Barent Roth

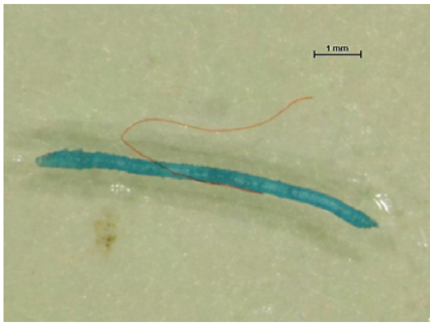
B Visually Identifying Plastics

Credit to Max Liboiron, 2015

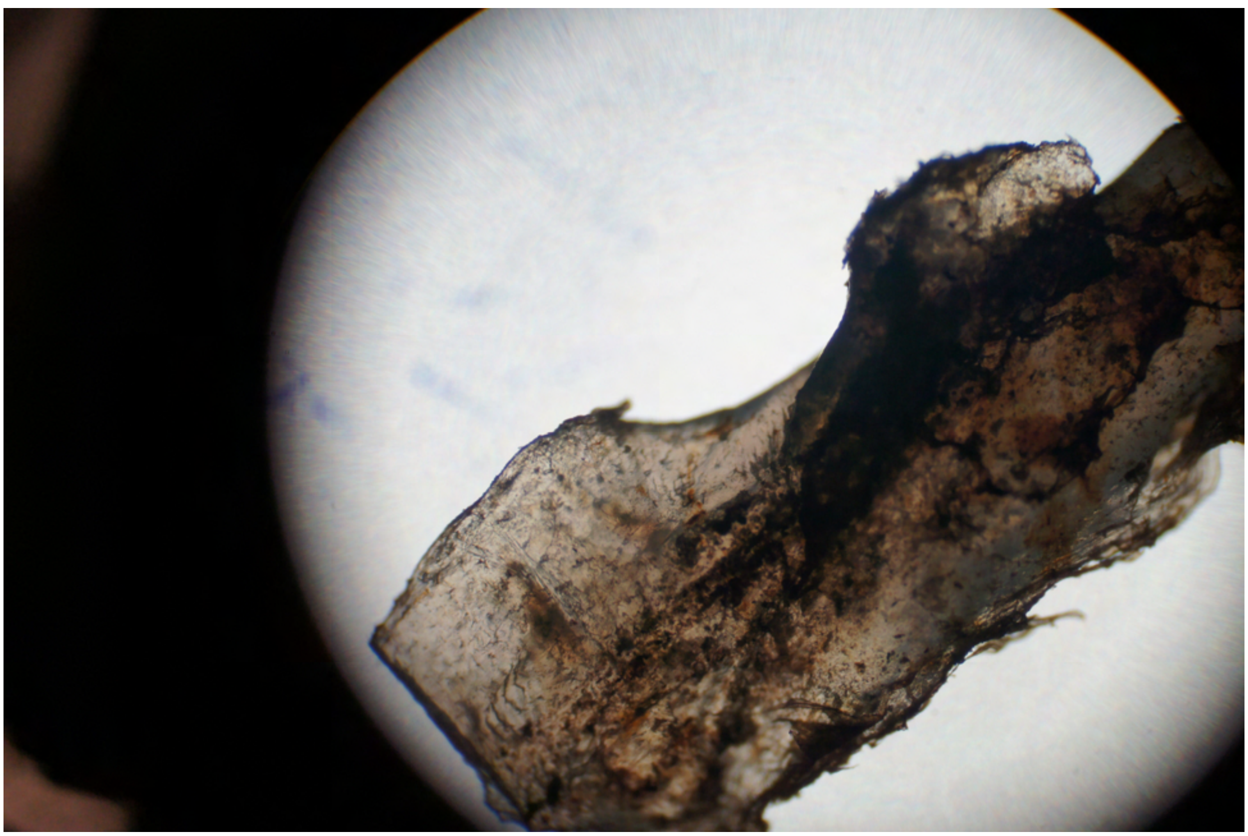
Fragment



Thread

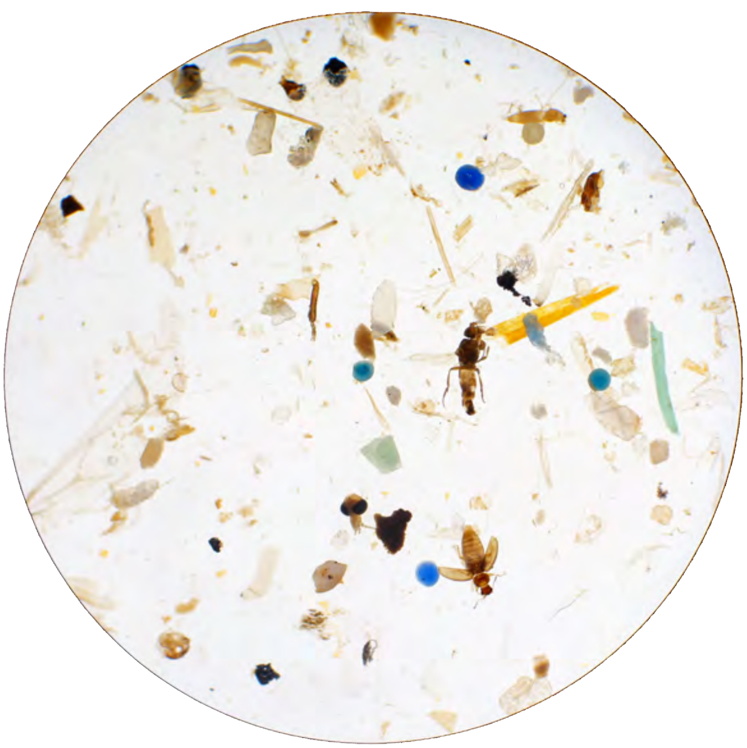


Film



Pellet (industrial stock)

Microbead



Erosion

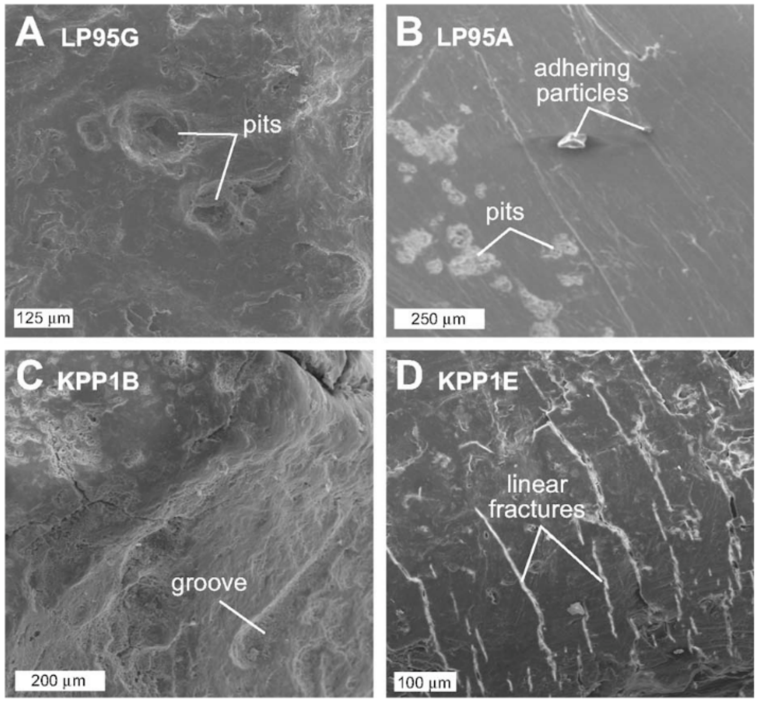
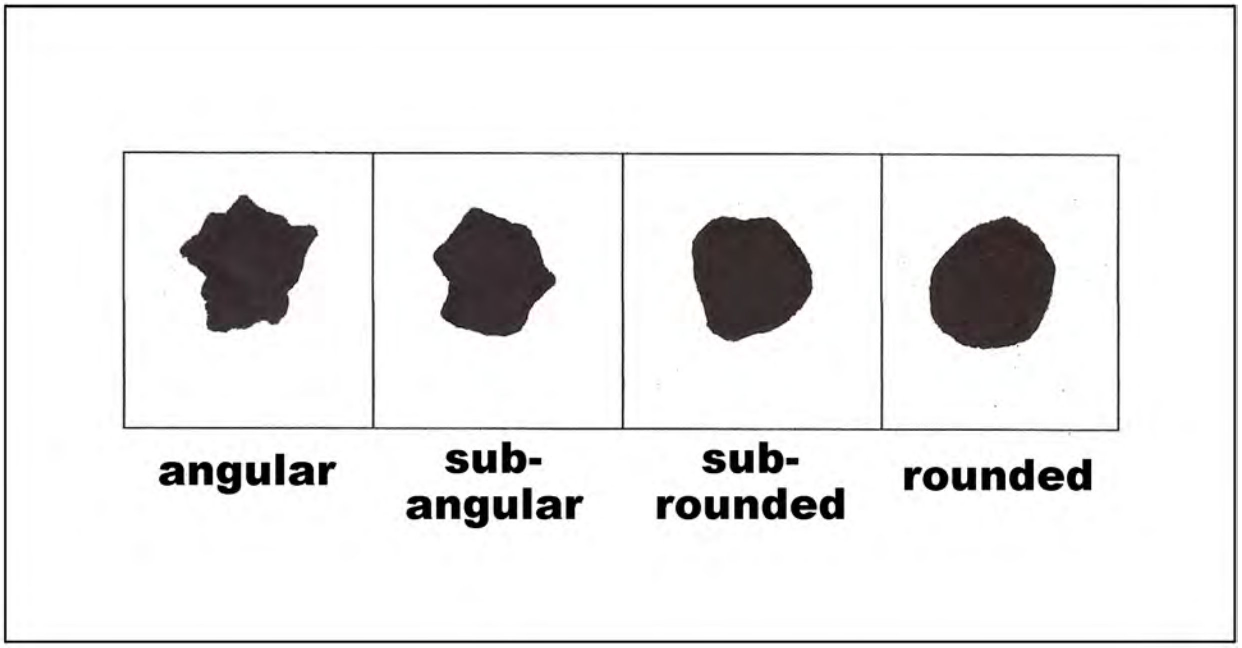


Fig. 2. Examples of surface textures on sampled plastic particles. (A) Pitted surface on rounded sample LP95G. (B) Adhering particles and pits on angular sample LP95A. (C) Groove in rounded, highly oxidized sample KPP1B. (D) Linear fractures in subangular sample KPP1E.

Above Erosion image:

Corcoran, P. L., Biesinger, M. C., & Grifi, M. (2009). Plastics and beaches: A degrading relationship. *Marine Pollution Bulletin*, *58*(1), 80-84. doi:10.1016/j.marpolbul.2008.08.022

Describing Fragment Shapes



C Holyrood Raw Data

Trawl testing in Holyrood, NL, with Costal connections. Trawls were dragged off an arm, staying out of the wake of the ship. Trawl times were approx 20 minutes. Trawl trails that were scratched due to malfunctioning trawls or contamination from trawl are included here and greyed out.

Trawl ID	Lat in	Long in	Lat out	Long out	Total distance-app1 (km)	flow meter count	flow meter distance (km) (FM count*rotor constant/999999000)	aprox time (min)	total # plastics
MantaJr2	47º26.129	053º07.640	47º25.788	053º07.625	2.58	N/A	N/A	23:20	N/A
LADI1	47º23.827	053º09.177	47º23.8747	053º09.109	3.64	86,075	2.31		N/A
MantaJr1	47º23.827	053º09.177	47º23.8747	053º09.109	3.64	86,075	2.31		N/A
BabyLegs1	47º234.043	053º08.792	47º25.167	053º07.762	2.58	77,536	2.08	21:07	N/A
LADI2	47º23.789	053º09.231	47º23.897	053º09.162	2.51	66,527	1.79	23:59	3
LADI3	47º234.043	053º08.792	47º25.167	053º07.762	2.58	77,536	2.08	21:07	7
LADI4	47º25.814	053º07.637	47º26.081	053º07.617	2.65	80,688	2.17	12:11	19
LADI5	47º26.141	053º07.689	47º25.858	053º07.617	2.39	73,212	1.97	22:21	3
LADI6	47º25.635	053º07.601	47º24.617	053º08.360	2.2	69,013	1.85	20:54	11
							Note: three options for rotor constant (26873, 57560, 51020). 26873 give lowest SSE compared to app1.	**TOTAL PLASTICS:**	43

mouth width (cm)	total surface area according to app1 (m^2)	plastics/m^2 (app1)	total surface area according to flow meter (m^2)	plastics/m^2 (flow meter)	notes
31.496					Contaminated, Cleaner water?
31.496					Close to sewer outflow; initial test null
31.496					Trawl was In wake
31.496					
31.496	790.5496	0.0038	563.08	0.0053	
31.496	812.5968	0.0086	656.26	0.0107	
31.496	834.644	0.0228	682.94	0.0278	
31.496	752.7544	0.0040	619.66	0.0048	
31.496	692.912	0.0159	584.12	0.0188	Choppy
	AVERAGE PLASTICS/M^2 (app1):	0.0110	**AVERAGE PLASTICS/M^2 :**	0.0135	
			AVERAGE PLASTICS/M^2 (standard speed rotor constant 26,873):	0.0135	
			AVERAGE PLASTICS/M^2 (low speed rotor constant 57,560):	0.0063	
			AVERAGE PLASTICS/M^2 (low speed rotor constant 51,020):	0.0071	

Trawl ID	Plastic ID	Plastic type	Plastic colour	secondary color	tertiary colour	Plastic longest measure (length mm)	plastic 2nd measure (height)	plastic smallest measure (width)	plastic weight (g)	plastic errosion	notes
LADI4	Eg. LADI4.A	(fragment, thread, film, microbead, pellet)									
LADI4	LADI4.1	fragment	blue	gray		4.27	1.75	0.06	0.0006	jagged edges,textured w	might be paint or adhesive
	LADI4.2	fragment	blue			0.37	0.15	X	X	jaggededges	may be pieces from LADI4.1, found in a feather, lost sample before widht/weight
	LADI4.3	thread	green			2.65	1.75	0.04	0.0002	discoloured,	In a loop shape (different height and width)
	LADI4.4	thread	blue			1.26	0.59	X	X		In a U shape, lost sample before width/weight
	LADI4.5	thread	red			1.68	0.57	X	X		lost
	LADI4.6	fragment	green			1.75	1.05	0.01	<0.0001	discolored, faded, jagge(	unable to register the weightt
	LADI4.7	fragment	red			1.01	0.45	0.05	0.0003	discoloured,	
	LADI4.8	thread	blue			0.99	X	X	X		lost
	LADI4.9	thread	blue	gray		1.25	0.72	0.23	0.0005		very tangled up in a ball
	LADI4.10	thread	red			0.46	0.03	0.03	<0.0001		too small to weigh
	LADI4.11	thread	blue			0.7	0.01	0.01	<0.0001		too small to weigh
	LADI4.12	thread	blue			1.37	0.41	<0.01	<0.0001	faded	too small to weigh, curled up
	LADI4.12	fragment	blue			1.27	0.5	<0.01	<0.0001		broke in two during analysis
	LADI4.13	thread	black			1.58	1.25	<0.01	<0.0001		too small to weigh, V shape
	LADI4.14	fragment	black			0.54	0.49	0.32	<0.0001	jagged, irregular surface	too small to weigh, porous
	LADI4.15	thread	black			1.67	1.04	<0.01	<0.0001		too small to weigh
	LADI4.16	thread	gray			0.39	<0.01	<0.01	<0.0001		
	LADI4.17	thread	gray			1.08	<0.01	<0.01	<0.0001		
	LADI4.18	thread	blue			1.1	<0.01	<0.01	<0.0001		
	LADI4.19	fragment	blue			0.14	0.12	<0.01	X	some areas more transp	sample was lost
	LADI4.20	thread	black			3.31	<0.01	<0.01	<0.0001		
	LADI4.21	thread	black			4.21	<0.01	<0.01	<0.0001		
	LADI4.22	fragment	blue			4.25	1.85	0.11	<0.0001		
	LADI4.23	fragment	blue			1.34	0.54	0.1	<0.0001		
LADI6	LADI6.1	thread	black			0.89	<0.01	<0.01	<0.0001		too small to weigh
	LADI6.2	fragment	black			1.51	0.82	<0.01	<0.0001		angular, jagged egdes. May have lost it.
	LADI6.6	thread	green			1.12	0.8	0.04	0.0001		like fishing line
	LADI6.7	fragment	white			1.33	1.02	0.2	0.0004	anuglar, discoloured	
	LADI6.8	fragment	white			0.82	0.78	0.06	0.0005	anuglar, discoloured	May be piece from 6.7
	LADI6.9	fragment	white			X	0.34	X	X	anuglar, discoloured	lost
	LADI6.10	fragment	green			0.51	0.31	0.02	<0.0001	angular	looks like fragment of fishing line
	LADI6.11	thread	blue			2.77	0.01	0.01	<0.0001		too small to weigh, frayed end
	LADI6.12	thread	red			3.08	0.01	0.01	<0.0001		too small to weigh, folded over (eg. 2 x length)
	LADI6.13	thread				1.43	0.73	<0.01	<0.0001		too small to weigh, curled up, frayed ends
	LADI6.14	thread	blue			1.87	0.01	<0.01	<0.0001		too small to weigh
	LADI6.15	thread	blue			0.78	0.26	<0.01	<0.0001		too small to weigh, U shape, frayed end
	LADI6.16	thread	blue			0.59	<0.01	<0.01	<0.0001		too small to weigh, U shape

	LADI6.17	thread	blue			0.48	<0.01	<0.01	<0.0001		there are a lot of blue threads; they don't appear to have been a part of the same sample, there is a diversity of blue shades
	LADI6.18	thread	blue			0.23	<0.01	<0.01	<0.0001		
	LADI6.19	thread	blue			0.46	<0.01	<0.01	<0.0001		
	LADI6.20	fragment	blue	gray		0.88	0.1	<0.01			
	LADI6.21	thread	blue			0.73	0.54	<0.01	<0.0001		too small to weight, U shape
	LADI6.22	thread	black			0.49	0.3	<0.01	<0.0001		tangled up; measured the ball (not thread stretched out)
	LADI6.23	thread	red			0.75	0.39	<0.01	<0.0001		
LADI3	LADI3.1	fragment	white	black		24.36	13.06	0.07	0.0151	some ink rubbed off, edg	label, contamination from LADI, Digits look like "RLN104P-2.."
	LADI3.2	fragment	white			6.71	1.86	0.13	0.0006		broke off from LADI3.1, straight edge
	LADI3.3	thread	blue			23.66	0.19	0.19	0.0017		fishing line, end is melted (black and yellow)
	LADI3.4	fragment	white			2.18	1.84	0.12	0.0001		piece of LADI3.1
	LADI3.5	thread				0.86	<0.01	<0.01		frayed end	
	LADI3.6	thread	red			0.92	<0.01	<0.01	<0.0001		
	LADI3.7	thread	black	red	transparent	1.53	1.4	0.02	0.0002		ball of multiple threads
	LADI3.8	thread	blue			2.17	0.12	X	<0.0001		measured length and width of thread
	LADI3.9	thread	black			1.44	0.62	<0.01	<0.0001		
	LADI3.10	thread	red			1.53	0.48	<0.01	<0.0001		too small to weigh
LADI2	LADI2.1	thread	blue			1.09	<0.01	<0.01	<0.0001		too small to weigh
	LADI2.2	thread	blue			1.06	<0.01	<0.01	<0.0001		
	LADI2.3	thread	blue			0.75	<0.01	<0.01	<0.0001		
	LADI2.4	thread	pink			1.95					
	LADI2.5	thread	red			1.59					
	LADI2.6	thread	blue			2.36	1.47	X	<0.0001		Thread coiled into a circle
	LADI2.7	thread	black			3.22	1.55	<0.01	<0.0001		Tread bent into "C"
	LADI2.8	thread	blue			1.81	1.49	<0.01	<0.0001		Tread bent into oval
LADI5	LADI5.1	thread	black			9.63	1.61	0.03	0.0011		in a U shape
	LADI5.2	thread	black			2.13	<0.01	<0.01	<0.0001	frayed end	
	LADI5.3	thread	black			2.27	<0.01	<0.01	<0.0001		

D Stats for Holyrood Data

Quantitative Analysis – LADI trawl in Holyrood
For Max Liboiron
Louis Charron – August 2016

OBJECTIVES

1. How much plastic is in the total water sampled, per square meter? Based on the width of the trawl mouth and the distance travelled, to double check.
2. Trawl 1,2, and 3 were in a different location than 4,5, and 6. Do they group that way? Or is the plastic content in that area fairly continuous?
3. Is the difference in the final distance for the flowmeter distance is statistically different from the distance measured by the "app".

METHODS

1. To calculate the amount of plastic per trawl (#/m^2), we use the formula:
   a. $Plastic(\#/m^2) = \frac{plastic(\#)}{[distance(km) \bullet 1000] \times [mouth.width(cm) \bullet 0.01]}$
2. Perform an ANOVA with 1,2,3 being one area and 4,5,6 another area. The model is written this way:
   a. Plastic content ~ Area
3. Perform a t-test on the distance difference between the flowmeter and the "app". If there is no difference, the difference will not be statistically different from 0.

RESULTS

1. Verification of the amount of plastic per trawl. The calculations were all good.

Table 1 – Surface area and plastic density per trawl for the LADI trawl

	Total surface area with app (m^2)	**Plastic density with app (plastic/m^2)**	**Total surface area with flowmeter (m^2)**	**Plastic density with flowmeter (plastic/m^2)**
LADI 1	1146.4544	NA	728.53	NA
LADI 2	790.5496	0.0038	563.08	0.0053
LADI 3	812.5968	0.0086	656.26	0.0107
LADI 4	834.644	0.0228	682.94	0.0278
LADI 5	752.7544	00040	619.66	0.0048
LADI 6	692.912	0.0159	584.12	0.0188

2. There is no difference between trawling 1, 2 & 3 and 4, 5 & 6. The area is fairly continuous. Note: There was no plastic data for trawling 1.

```
> summary(Area)

Call:
lm(formula = plastics.flowmeter ~ Area, data = Holyrood)
```

```
Residuals:
        2         3         4         5         6
-0.002700  0.002700  0.010667 -0.012333  0.001667

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 0.008000   0.006871   1.164    0.328
Areab       0.009133   0.008870   1.030    0.379

Residual standard error: 0.009717 on 3 degrees of freedom
  (1 observation deleted due to missingness)
Multiple R-squared:  0.2611,  Adjusted R-squared:  0.01483
F-statistic:  1.06 on 1 and 3 DF,  p-value: 0.3789

> anova(Area)
Analysis of Variance Table

Response: plastics.flowmeter
          Df     Sum Sq    Mean Sq F value Pr(>F)
Area       1 0.00010010 1.0010e-04  1.0602 0.3789
Residuals  3 0.00028325 9.4416e-05
```

Table 2 – Statistical description of both trawling area: 1, 2 & 3 and 4, 5 & 6

Trawl	**Mean**	**SD**	**n**	**SE**
1,2,3	0.008	0.004	2	0.002669
4,5,6	0.017	0.012	3	0.006686

3. There is a difference between the distance measured by the flowmeter and the app. On average, the app measured a distance 0.633km (SD: 0.363km) longer than the flowmeter.

```
> model.distance

     One Sample t-test

data:  Holyrood$distance.diff
t = 4.2701, df = 5, p-value = 0.007938
alternative hypothesis: true mean is not equal to 0
95 percent confidence interval:
 0.2520737 1.0145930
sample estimates:
mean of x
0.6333333
```

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