

Developing a methodology to evaluate different age classes of anti-predator netting used in the shellfish aquaculture around Denman Island in British Columbia, Canada

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Abstract

Shellfish aquaculture uses various kinds of plastic equipment and is a potential source of microplastic pollution which threatens the marine environment. Shellfish farmers on Denman Island would like to know at which age anti-predator netting should be removed to minimize the release of plastics into the ocean. This project focuses on the degradation rate of anti-predator netting used in shellfish aquaculture and consists of two major components. First, the mechanical properties (ultimate tensile strength and elongation) of anti-predator netting of different ages will be tested. A clear difference is seen for the ultimate tensile strength between the 0-year-old netting (mean $\pm$ standard deviation: 64.3 ± 3.7 N) and the 2-, 6- and 15-year-old nettings who find themselves in rather the same area (respectively 31.8 ± 3.9 , 22.8 ± 4.2 and 25.4 ± 5.7 N). Here, a statistically significant difference is seen between the 0-2, 0-6, 0-15, 2-6, 2-15 and 6-15-year-old netting (respectively $P = 1.7\text{E-}18$, $3.1\text{E-}21$, $6.2\text{E-}24$, $5.7\text{E-}33$, $2.5\text{E-}15$ and $5.4\text{E-}04$). A significant difference is also witnessable within the tidal sections of the 2 and 6-year-old netting ($P\text{-value} = 3.5\text{e-}03$ and $3.2\text{E-}05$). In both cases, a statistically significant difference is witnessable between the high-low ($5.8\text{E-}03$ and $5.4\text{E-}06$) and mid-low ($4.5\text{E-}04$ and $3.5\text{E-}03$) sections of the APN. There is no difference in the high-mid sections of these two APN.

As for the elongation, a significant reduction is observed with increasing age of the netting (0-year-old: 12.1 ± 2.2 , 2-year-old: 11.3 ± 1.8 , 6-year-old: 9.6 ± 2.1 and 15-year-old: 6.3 ± 1.9 cm).

Second, these nettings will be tested for leaching dissolved polymers and microplastic particles to their environment. Unfortunately, these results are not included in this report as the analysis of these samples could not be completed in time, although a reduction in mass was observed (whether or not caused by residual biofouling on the samples). The 0 and 2-year-old netting (respectively 0.0023 ± 0.0066 and 0.0019 ± 0.0316 g) show very different results in comparison to the 6 and 15-year-old netting (respectively 0.0391 ± 0.0062 and 0.0388 ± 0.0045 g).

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1 Introduction

1.1 Plastics

Plastics bring significant benefit to modern day society thanks to their low cost, light weight and durability (Yang et al., 2021). However, plastic pollution is also one of the greatest environmental concerns to the present world. In the last two decades, plastic production reached 460 million metric tons, and less than 10 % gets recycled. The rest is burned, buried, or ends up in the environment. It has been stated that on a weight estimate, there will be more plastic than fish in the oceans by 2050.

Plastics appear in various forms such as foils, foams, fibers, pellets, fragments and microbeads. The chemical composition of MPs is diverse. Polyamide (PA), polyvinylchloride (PVC) and polyethylene terephthalate (PET) have higher densities than seawater which results in higher settlement rates in sediments, while polystyrene (PS), polyethylene (PE), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP) and polyurethane (PUR) have lower densities and float on seawater (Yang et al., 2021).

Plastic marine debris has arisen as a worldwide environmental concern, becoming omnipresent in all marine ecosystems. MPs in the ocean originate from the decomposition of marine plastic waste, leaching of river or land-based waste, plastic waste from marine tourism and shipping, fishing and aquaculture gear, and atmospheric deposition. Current estimates consider that ca. 4.8 - 12 million tons of plastics enter the ocean annually (Chen et al., 2021).

Fisheries and aquaculture industries form a source of marine plastic pollution due to use of plastic equipment. For example, shellfish aquaculture requires the use of ropes, rafts, floats, and trays that are usually composed of polystyrene, polypropylene, PVC, or HDPE. Numerous studies have shown that MPs are present in marine organisms such as fish (Ferreira et al., 2018; Wootton et al., 2021), bivalves (Bråte et al., 2018; Truchet et al., 2021) and crustaceans (Botterell et al., 2019; Yin et al., 2022). Recent studies even suggest that these species transfer the MPs trophically throughout the marine food webs (Welden et al., 2018; Carbery et al., 2018). Coastal areas show the highest concentrations, while concentration drops abruptly in the open sea. Exposure depends on the feeding strategy and trophic level of the organisms (Chen et al., 2021).

Filter feeders tend to ingest MPs that resemble the physical properties of the material they feed on. Humans ingest thousands of MPs through seafood consumption. These numbers vary with the prevalence and type of seafood consumed (Cox et al., 2019). Long term exposure to MPs causes many different effects such as lower growth rates, hindered reproductive capacity and behavioral changes (Ribeiro et al., 2017). Larvae are the most vulnerable to MP ingestion during the early development stages, here particle size is an important parameter (Cole & Galloway, 2015). MPs can also degrade further into even smaller particles called nano plastics (NPs), and are characterized by a size of less than 100 nm (Feng et al., 2020). They appear to be more effective in transferring to tissues, organs, and the circulatory system, leading to damage on a cellular level. Larger particles appear to be digested more easily (Jacob et al., 2020). MPs enhancing the velocity of dispersion of pathogenic species in a marine environment (Naik et al., 2019). Some plastic fragments may even act as a carrier for toxic chemicals such as bisphenol As (BPA) that can damage ecosystems when they accumulate (Geburzi & McCarthy, 2018; Hermabessiere et al., 2017).

Also, recent studies identified that MPs are even present in human blood, lung tissue and placenta. PE, PP, PET and polymers of PS were the most encountered here (Leslie et al., 2022; Jenner et al., 2022 and Ragusa et al., 2021). They can even cross many biological barriers and destabilize lipid membranes (last cell protective barrier) (Fleury & Baulin, n.d.). A diet rich in organisms of lower trophic levels can increase the ingestion of MPs. This is mainly linked to the higher concentrations of MPs identified but also the fact that smaller sea creatures are often consumed with intestines, where the MPs are digested.

1.1.1 Degradation mechanisms

Degradation is a physical or chemical effect that causes changes in the molecular structure of plastic polymers. Because the mechanical integrity of plastics is highly dependent on their average molecular weight, degradation weakens the material. Plastics will fragment into smaller plastic particles called microplastics (MPs), and are characterized by a size of 0.5 - 5 mm. They impact the marine environment by being ingested by organisms. When MPs degrade completely, this process is referred to as complete mineralization. The degradation rate of plastic equipment in an aquatic environment is accelerated by numerous environmental factors.

The major causes of degradation identified are photo-oxidation, abrasion, chemical oxidation, and microbial adhesion and colonization (Wagner & Lambert, 2018).

1.1.1.1 Photodegradation

Plastics often contain additives that hold chromophores that absorb radiation in the near UV-region of light. Yellowing of the polymer during its lifetime is an indication of the presence of these chromophore groups (Gardette et al., 2013). Near UV absorbing conjugated groups are often present on the surface of plastics; these are likely to induce photo-oxidation under the influence of UV-light and oxygen. Photo-oxidation generally includes four major reaction types: chain initiation, chain growth, branch formation and chain termination. A chromophore group will absorb more UV-light, induce more initiation reactions, produces more radicals and thus accelerate aging. Solar radiation can also change surface characteristics such as morphology and roughness of the MPs, which further accelerates breakdown. Photo-oxidation is identified as the dominant degradation mechanism in the breakdown of plastics exposed to sunlight. Radiation type and intensity are the most influencing parameters. UV radiation is classified according to wave range into UV-A (320-400 nm), UV-B (275-320 nm), UV-C (200-275 nm) and UV-D (100-200 nm). It is primarily UV-B radiation that initiates photo-oxidative degradation.

Once initiated, the degradation can also proceed thermo-oxidatively for a certain time without the need for exposure to sunlight. This autocatalytic degradation process can progress as long as oxygen is available to the reaction. During degradation, the molecular weight of the polymer is decreased, and oxygen-rich chromophore and functional groups are formed in the polymer (Sun et al., 2020).

1.1.1.2 Mechanical degradation

Other types of degradation mechanisms are much slower compared to light-induced oxidation. This is a form of physical degradation where the material is abraded due to friction with other substances (Suhrhoff & Scholz-Böttcher, 2016), such as waves, sand, stones or other particles.

1.1.1.3 Chemical degradation

Once photo-oxidation has begun, chemical degradation occurs in the marine environment. Plastics in a wet environment can interact with reactive oxygen species under the influence of environmental stressors and induce chemical deterioration.

For example, abiotic hydrolyses of functional groups like esters, amides and carbonates, facilitated by alkalinity of seawater and OH⁻ ions severs the large molecules in a process called chain scission. Due to the lack of functional groups on its surface, polyethylene is more resistant to abiotic hydrolysis (Min et al., 2020).

1.1.1.4 Biodegradation

Micro-organisms colonize plastic particles and promote biodegradation and biotransformation by adhering to the surface and the formation of biofilms. This process is called biofouling. First, a biofilm will develop, followed by an algal mat, and later invertebrates. The fouling rate strongly depends on the environmental conditions and season of exposure (Andrady, 2011). Microorganisms' adherence to the plastic surface changes the properties of the material such as hydrophilicity and adhesion characteristics. The leaching of additives in monomers out of the plastics by cell and enzyme degradation is increased. Then, the enzymes or biological radicals attack the leached compounds, leading to embrittlement and loss of mechanical stability. A biofilm can mask the surface properties, degrade the additives, attack the polymer surface, and release metabolic biochemical substances.

1.2 Shellfish aquaculture in BC

Two main species of shellfish are cultured in BC: The Pacific oyster (*Magallana gigas*) and the Manila clam (*Tapes philippinarum*) (Figure 1). Other less present species are scallops (*Patinopecten yessoensis*), mussels (*Mytilus spp.*), geoducks (*Panopea generosa*) and abalones (*Haliotis spp.*). This project is focused on the Manila clam, which was accidentally introduced in the mid-1930s, and has since become well established in BC. Clam seed is produced at a hatchery, often purchased from nurseries and directly spread on the mud-gravel grow-out beaches as an intertidal method (Figure 1). The intertidal method refers to farming systems where clams are exposed to air during low tide in each tidal cycle, and water during high tide. The tide cycle occurs two times a day with approximately 12 h high tide and 12 h low tide. Due to predation by crabs and ducks, plastic anti-predator netting (APN) is laid down and secured at eight spots across the grow-out plot of these young clams. Here, clams with a size of approximately 5 cm are harvested once a year (every section once a month), at low tide, using rakes or scrapers to get them out of the substrate and collect them by hand (Holden et al., 2019). Inspections are carried out three times a year: before winter, after spring and in the summer.

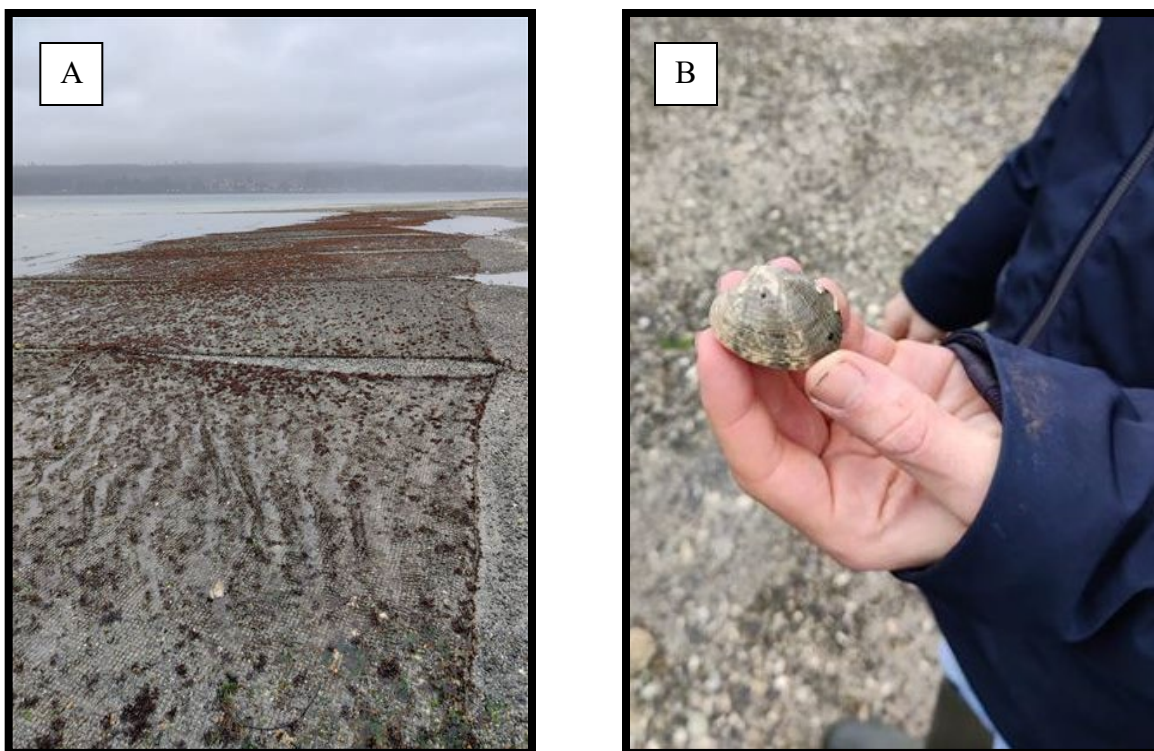


Figure 1. A: Intertidal shellfish farming on Denman Island (BC, Canada). B: A Manila clam that is protected by the netting from predators like ducks.

1.2.1 Anti-predator netting

Shellfish farms in Baynes Sound and other areas of the province often secure nets on the tenured beach to cover the areas that have been seeded with Manila clams. Usually, a strong and lightweight plastic netting, with mesh size around 1.6 - 1.9 cm, is placed over the seeded, natural substrate. This netting has three primary functions. First, to protect the clams from predation; Second, to assist in stabilizing the substrate, and third, to increase natural recruitment of clam seed by slowing water movement at the surface. Concern has been raised by some regulatory agencies that this netting is a potential source of plastic pollution due to extensive and prolonged use (Carswell et al., 2006).

The anti-predator netting (APN) collected from Denman Island is made of pure PE and is used to protect manila clams against predators. Due to primarily photo- and mechanical degradation, the APNs shed MPs into the water which are ingested by marine organisms. APN breaks after 15 years and are then replaced, but they can also afford it to replace them for e.g. after 10 years, as the price of the netting and setting it up costs around 250 Canadian Dollars (CAD).

The project aims to find the point where these nettings should be removed to mitigate MPs output. Therefore, evaluating the APN of different classes (age 0, 2, 6 and 15) will be tested on their mechanical properties like the ultimate tensile strength (UTS) and elongation. Second, any dissolved polymers and a MPs count will be carried out on the same APN.

1.3 Mechanical properties

It is important to be familiar with the basic mechanical properties of a certain material before working with them. It provides information about the strength, toughness, and elasticity of a material. Tensile properties are a group of mechanical properties that are composed of the reaction of a material to resist applied tension forces. Tensile properties vary from material to material and are determined through tensile testing, mostly with a universal tensile testing machine.

The tensile test produces a load versus elongation curve, which is then converted into a stress versus strain curve. Tensile testing is usually described in a standard, such as the international testing standard ISO 10319 (ISO - ISO 10319:2015 - Geosynthetics — Wide-Width Tensile Test, 2015).

The strength is the stress required to break a sample. There are several types of strength, but this project will focus on the ultimate tensile strength. This is the maximum stress a material can withstand while being stretched without breaking. The percentage elongation to break or ultimate elongation is the strain in the material upon breakage. The stress (σ) strain (ϵ) relation is often depicted in stress strain curves. The stress strain curve helps quantify certain mechanical properties of the material such as the Young's modulus, toughness and yield strength. After this point, the material will experience permanent deformation from higher stresses. Because of this, polymer materials experience two forms of deformation. When a stress is applied below the yield strength, the material will deform elastically, and it will return to its original shape when the stress is removed. When a stress higher than the yield strength is applied, the material will deform viscous and permanently (Balani et al., 2015).

1.4 Dissolved polymers

The rate determining step for polyethylene (PE) degradation in a natural environment is abiotic oxidation by exposure to ultraviolet (UV) radiation. This process can be divided into 3 steps: initiation, propagation and termination.

During the initiation phase, chemical bonds in the main carbon chain are broken by absorption of solar radiation to produce a free radical. PE doesn't contain the unsaturated chromophore groups, necessary for the absorption of UV-light. Consequently, PE is more resistant to photo-initiated degradation than other commonly used polymers in the fishing industry (e.g. PP and PVC). Still, it is prone to this form of degradation due to external impurities or abnormalities in the macromolecular structure. After initiation, peroxy radicals are formed due to polymer interaction with oxygen molecules in the propagation step.

Besides the formation of hydroperoxides, oxygenated low molecular weight fragments, like aliphatic carboxylic acid, alcohols, aldehydes, and ketones are formed due to autooxidation by complex radical reactions. Propagation ultimately leads to chain scission or crosslinking. Termination of the free radical mechanism occurs when an inert product is formed from the reaction of two radicals on the polymer surface. Due to oxidation, random chain scission or end-chain scission, branching, crosslinking and formation of oxygen-containing functional groups. Olefins, aldehydes and ketones are expected products of the radical termination reactions. Because these molecules contain unsaturated double bonds, they should be more susceptible to photo-initiated oxidation. As the molecular weight of the polymer is reduced, the material gets brittle and more susceptible to fragmentation which makes a higher surface area available for further interactions. Because of its relatively high molecular weight and the lack of functional groups, biodegradation is limited for PE in the first stages of usage (Wagner & Lambert, 2018).

Biodegradation increases with time because the polymer needs to be broken down first by abiotic mechanisms to smaller pieces. If the particles are too large, they cannot pass through the cellular membranes of micro-organisms. In addition, abiotic degradation produces carbonyl groups that increase the hydrophilicity of the polymer and thus increases its availability for biodegradation. The most common biodegradation products for PE are propane, propene, ethane, ethene, butene and hexene. Extensive biodegradation can result in shorter segments like esters and acids (Gewert et al., 2015).

2 Methods

2.1 Site description

Baynes sound is a shallow coastal channel of approximately 8700 ha in British Columbia, Canada. The channel is bordered by the east coast of Vancouver Island and partially bordered by the west coast of Denman Island. The nettings were collected at April 19th from a shellfish farm at Denman point, located on the west shore of Denman Island (Figure 2).

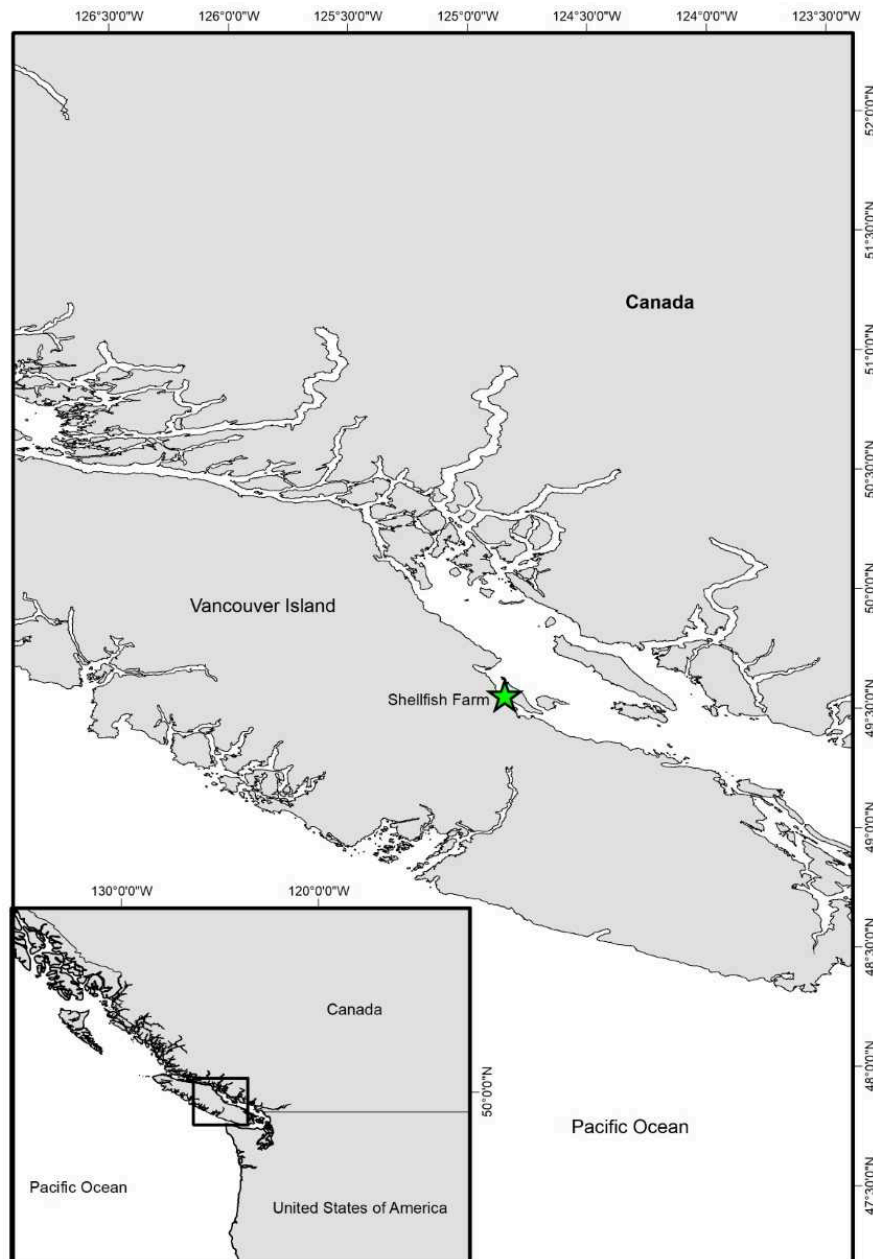


Figure 2. Shellfish farm on Denman Island where the 2-, 6- and 15-year-old netting were collected.

The 2- and 6-year-old nettings were collected from a farming site, south of Denman Point, sheltered from tidal currents and weather conditions (Figure 3A & B). While the 15-year-old netting was collected from a farming site at Denman Point, a high exposure area (Figure 3C & D) (Carswell et al., 2006). As stated before, the netting (Summer Breeze Aquaculture Products) is made of PE and has the following dimensions: $\pm L = 15$ m and $W = 4.40$ m. The zero-year-old or new netting was bought directly from the supplier as the other nettings and has not been used yet.

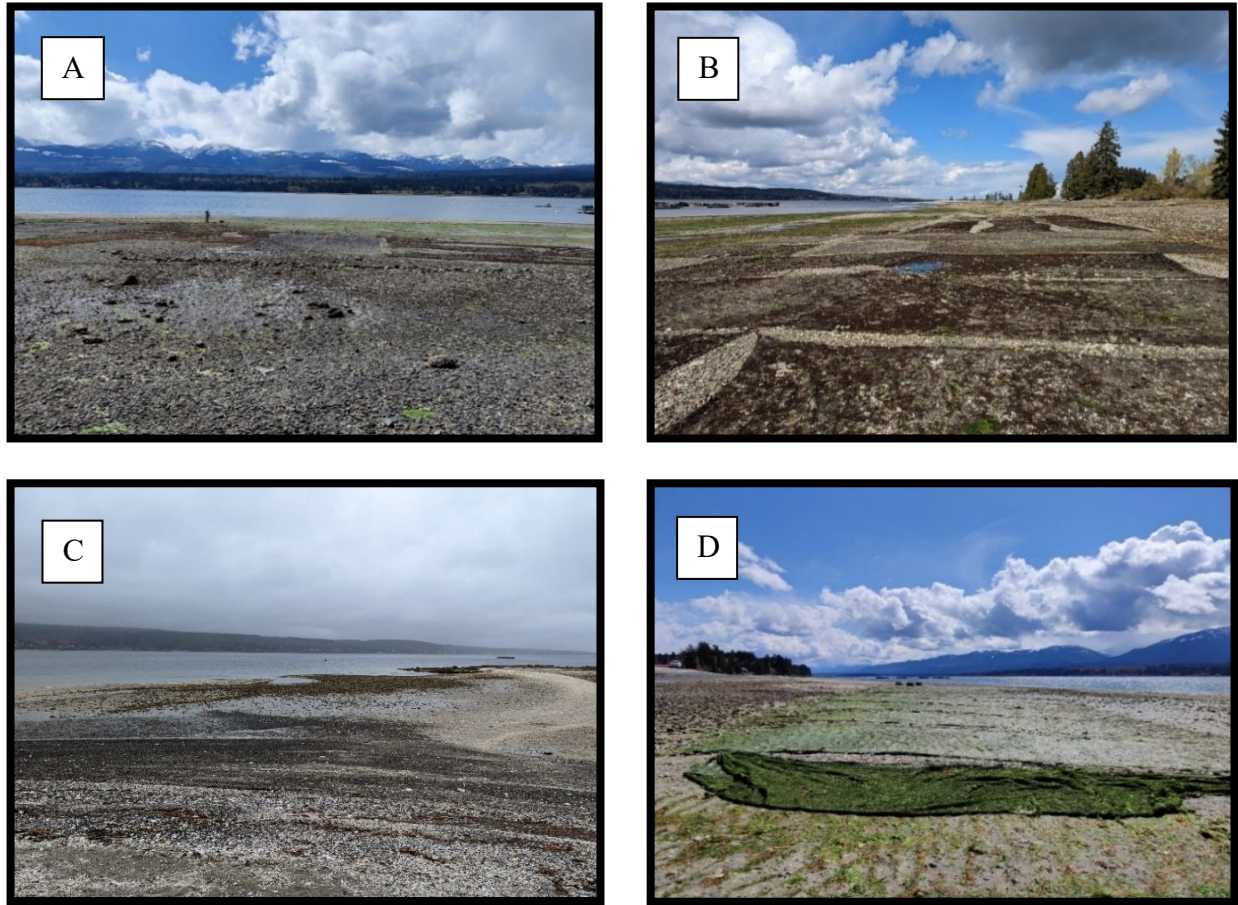


Figure 3. A & B: The less exposed area to the sun and wave action where the 2- and 6-year-old nettings were collected. C & D: The most exposed area where the 15-year-old netting was collected.

2.2 Sampling method

While collecting the 2-, 6- and 15-year-old netting, the side closest to the ocean (low tide) was tagged with orange flagging tape. This side served as the 15 m line. For each age of netting (0, 2, 6 and 15 years old), squares of approximately 50 by 50 cm were cut out at the 0, 3, 6, 9, 12 and 15 m lines; at the left, middle and right-hand sides of the net (Figure 4A).

When the netting showed severe damage (e.g., broken strings or shears) at a sampling spot, another spot was chosen as close as possible to the original. The individual samples were then tagged at the outer side and laid out to dry. After the drying process, each piece was photographed and logged (Figure 4B, Appendix 7.1).

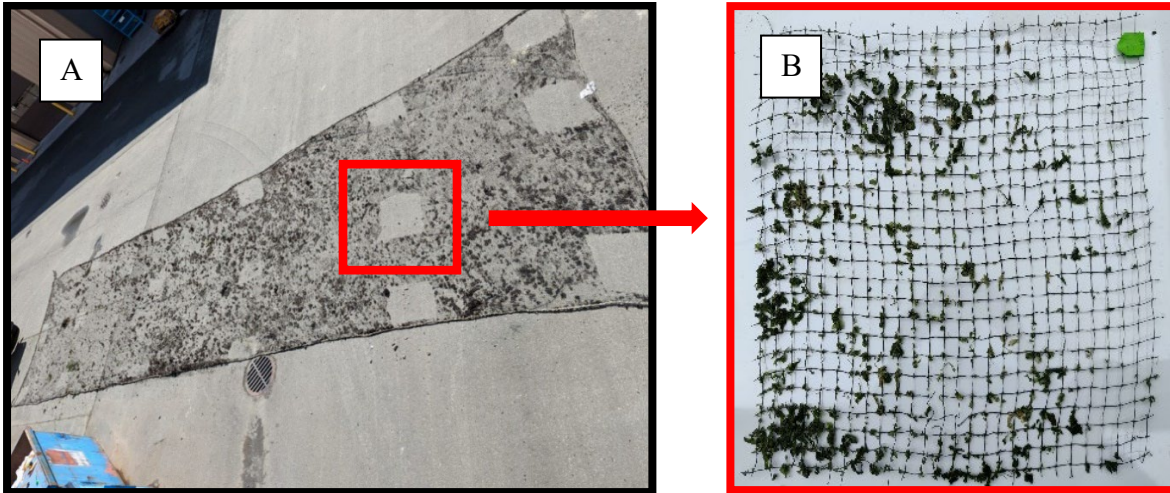


Figure 4. A: 50 by 50 cm squares cut out at the 0, 3, 6, 9, 12 and 15 m lines in each class of APN.

B: Tagged 50 by 50 cm squares after they have dried.

2.3 Mechanical properties

Due to budget limitations, the tensile testing device was built in house (Figure 5, Appendix 7.2). A wooden frame was constructed; Two vertical (120 x 8.5 x 4 cm) and two horizontal (50 x 14 x 4 cm) blocks of wood were attached to each other with two screws on each side. Two blocks (50 x 14 x 4 cm) were added in contact with the floor to give more support to the whole device and were attached to the lower horizontal block with two screws. Two triangle blocks (14 x 7.5 x 4 cm) were attached to this frame on the lower side with two screws each.

Three wooden blocks (24.5 x 8.7 x 4 cm) were stacked on top of each other with 4 screws fixed to the base. The winch (Motomaster), with a 1.6 hub diameter and 20 cm handle length, was put on top of these blocks with two screws. The winch was placed more to the left side of the upper block so that the sample could be pulled apart in the middle at the hub. The purpose of the winch is to extend the samples until their breaking point. A digital crane scale (Modern Step, 15.7 x 8.1 x 3 cm), with a stainless-steel rotary shackle at the top and rotary hook at the bottom, was attached at the top of the wooden frame to a stainless-steel U-bolt with nuts (Hillman, 13.5 x 8 cm).

A piece of rope (15 x 2.5 cm) with associated clamp (Mastercraft C-type, 5 x 4 cm) was hanging on the rotary hook to hold the sample on the top. Another piece of rope (64 x 2.5 cm) with associated clamp was attached to the winch to hold the sample on the other side. In each clamp, a small piece of wood (1.5 x 1.5 x 1.1 cm) was placed in the opening to ensure a straight downward pulling force.

A yard stick (100 cm) was attached at the back of the frame to measure the elongation of the sample, ensuring it was in line with the sample. To analyze all the data, two GoPro's measured the UTS (N) on the digital crane scale at the top and the elongation (cm) on the yard stick at the bottom. For the UTS, the GoPro was used and placed on a holder attached to one of the vertical wooden blocks. The GoPro and associated tripod were used to digitally document the elongation.

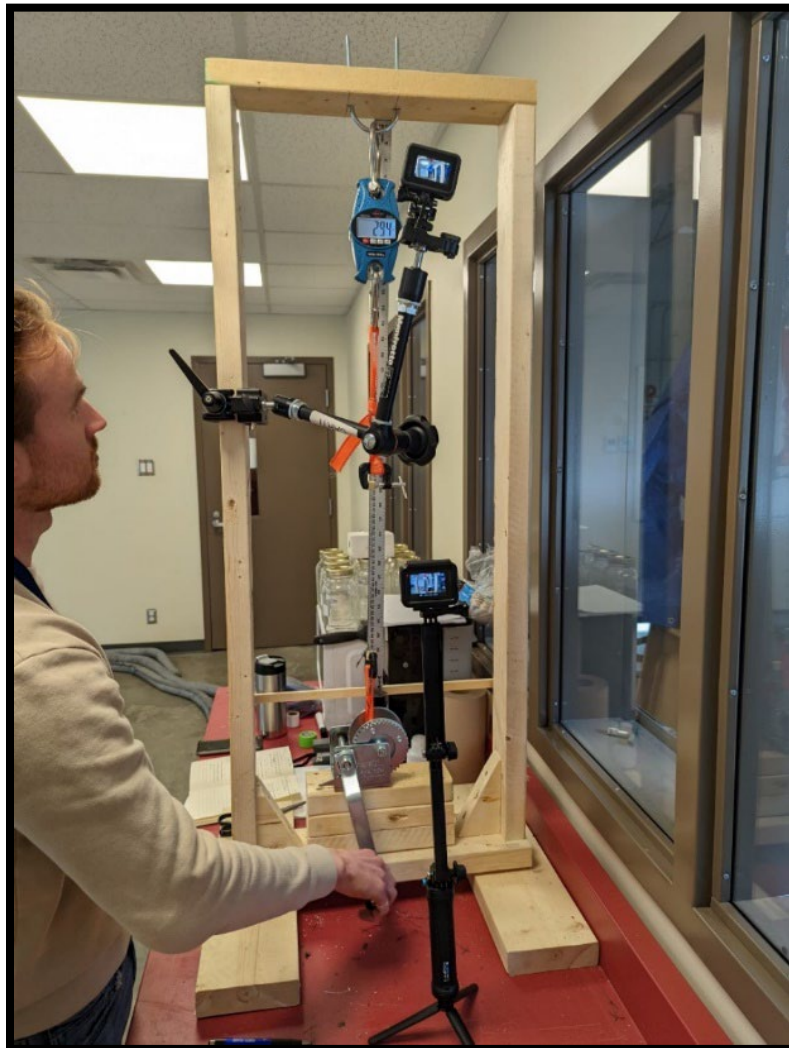


Figure 5. In house build tensile testing device to measure the UTS and elongation of APN in full action.

The tensile testing required five unbroken string subsamples of approximately 20 cm in length from each 50 by 50 cm samples (Figure 6). This did not apply to the new netting as it was unused and therefore completely uniform. Consequently, only 15 strings were cut out of the zero-year-old netting. This resulted in a total of 285 string samples to be tested. The sample was stretched until breakage and the UTS and elongation upon breakage serve as a measuring parameter for the mechanical properties. The following experimental procedure for tensile testing was based on the international testing standard ISO 10319 for geosynthetics: (ISO - ISO 10319:2015 - Geosynthetics — Wide-Width Tensile Test, 2015).

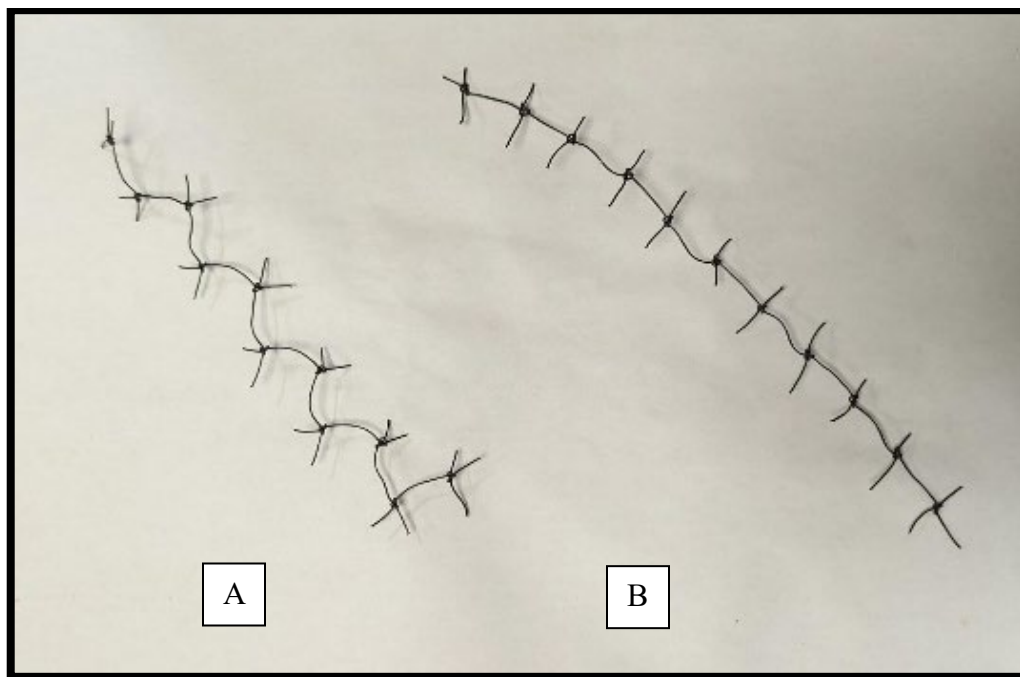


Figure 6. A: String samples for the 0-year-old netting. B: String samples for the 2, 6 and 15-year-old netting.

The two outer nodes of the sample were manually fixed in the two clamps with the previously mentioned small block of wood. A longitudinal force was exerted with the manual winch on the test specimen until it broke. The results were obtained through analysis of the video data obtained by the Go Pros.

2.4 Dissolved polymers and MPs count

This component of the project consisted of two identical trials. The first was used to detect any dissolved polymers that leached from the netting into the water, and the second to count and identify MPs. This part required squares with a size of 10 by 10 cm. For each age of netting, these 10 by 10 cm subsamples were selected from the 50 by 50 cm squares at the 0, 6 and 15 m line resulting in a total of 36 10 by 10 cm squares for each trial (appendix 7.3).

The 10 by 10 cm subsamples were treated to get rid of biofouling. Most fouling was initially removed by hand. Afterwards, each square was soaked for 1 hour in a 10 % NaOH solution to remove remaining fouling. While soaking, the jars were gently turned over every 15 minutes to ensure maximum contact between the basic solution and organic material. After soaking, the samples were rinsed three times with demineralized water to remove residual NaOH solution and laid out to dry. Once dry, all samples were weighed and rinsed before adding them to the mason jars.

In each trial, the dried 10 by 10 cm squares from the middle of the 0, 6 and 15 m line were put in a glass mason jar for each age of netting. Then, 50 g of rinsed play sand (CIL) and approximately 1 L of artificial sea salt water (Instant Ocean) was added to each jar. One jar was filled with only salt water and sand as a control. This methodology was executed in triplo for both trials. This resulted in a total of 30 glass mason jars, set up for the two trials. After set up, each mason jar was turned upside down, back and forth for 10 times, three times a day, at day 1, 5, 6 and 7 for three weeks.

After three weeks, the 10 by 10 cm subsamples were taken out of the jars and laid out to dry. After drying, the samples were weighed again to determine the loss of material during both trials. The remaining water samples from trial one was send to BV to analyze for dissolved polymers. This involves two environmental chemistry methods which are accredited under ISO/IEC 17025 to analyze the samples quantitatively. One of the tests involves the presence of volatile organic compounds (VOCs) and the other one of acids, bases and neutrals (ABNs). The water samples from trial two were send to the University of British Columbia's (UBC) Cluster for Microplastics, Health and Environmental to count MPs.



Figure 7. A: Setup for the dissolved polymers experiment. B: Setup for the MPs count experiment.

2.5 Statistical analysis

The statistical analysis was done with two separate tests on the UTS and the elongation. First, all data for the 0, 2, 6, and 15-year-old netting was rearranged into their respective age class. Then, an analysis of variance (ANOVA)-test was performed to investigate if there was a statistically significant difference between the average UTS and elongation for these classes. If the test indicated that there was a statistically significant difference between different classes ($P\text{-value} < 0.05$), the different age classes were compared with each other: An F-test was performed to investigate if the variances were significantly different. Subsequently, the proper post hoc test was performed (t-test: two sample assuming equal or unequal variances).

Second, all data for each age of netting was rearranged into three sections: low, mid and high tidal. The data from samples at the 0 and 3 m line were put together in the high tidal section, data for the 6 and 9 m line in the mid tidal section and data from the 12 and 15 m line in the low tidal section. The same ANOVA Single factor test was performed to compare the tidal sections for the 2, 6 and 15-year-old netting. If the ANOVA test indicated a significant difference, the tidal sections for that age of netting were compared with an F test and corresponding post hoc test.

3 Results

3.1 Mechanical properties

3.1.1 Ultimate tensile strength

The results for the tensile test show an average UTS of (64.3 ± 3.7) N, (31.8 ± 3.9) N, (22.8 ± 4.2) cm and (25.4 ± 5.7) N for respectively the 0-, 2-, 6- and 15-year-old netting (Figure 8).

The ANOVA-test between age classes resulted in 3 degrees of freedom between groups, 281 degrees of freedom within groups and a P-value of 1.7E-97. This indicates that there is a significant difference between the average UTS of the age classes. A post hoc-test (t-test: two samples assuming unequal variances) was carried out to make a comparison between different classes of APN (Table 1). All values indicate a significant difference for each comparison.

Table 1. Comparison of the UTS between different classes of APN and their corresponding P-values.

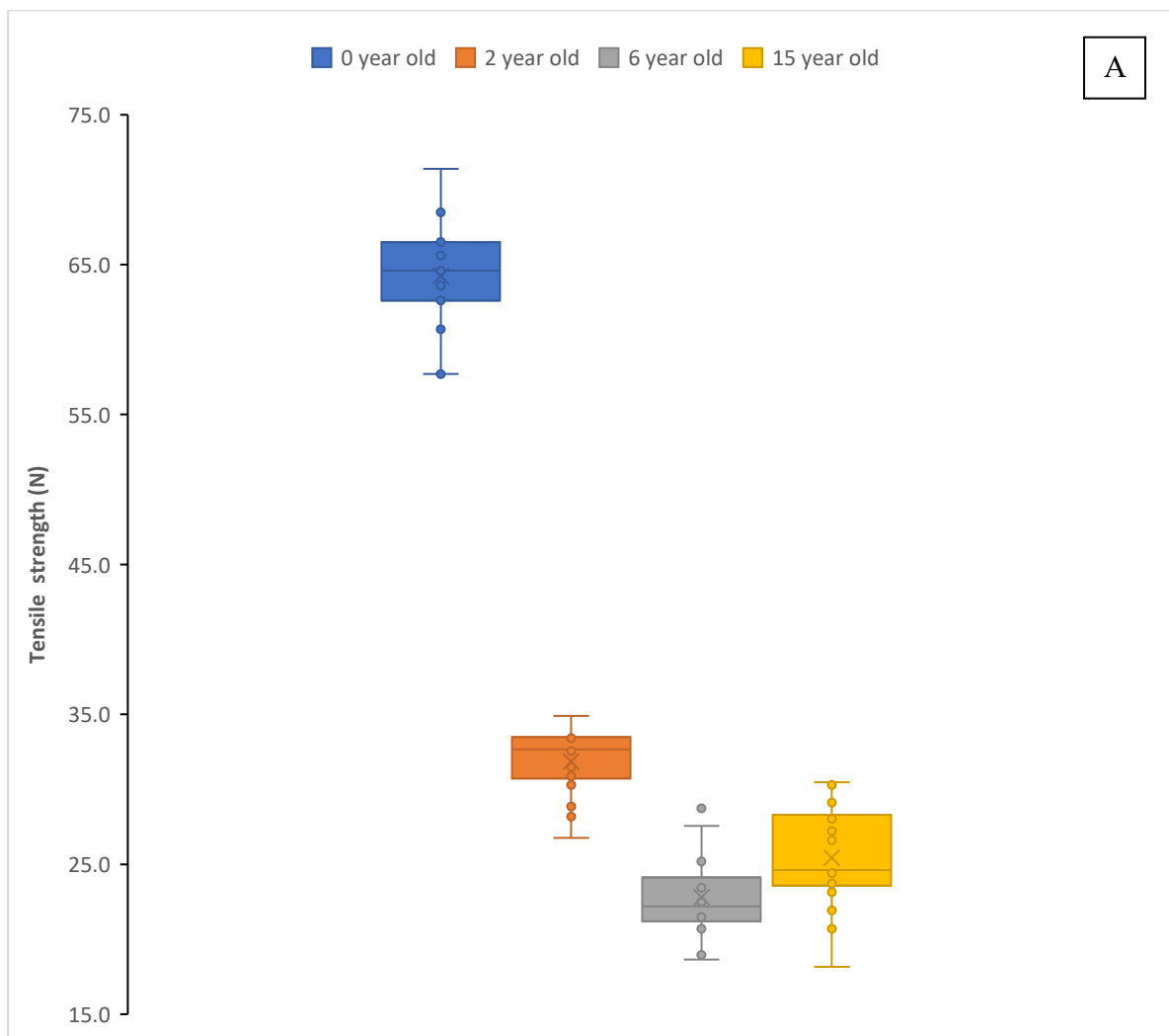
Comparison between different classes of APN (year old)	P-value
0-2	1.7E-18
0-6	3.1E-21
0-15	6.2E-24
2-6	5.7E-33
2-15	2.5E-15
6-15	5.4E-04

The ANOVA-test between tidal sections of the 2-year-old netting resulted in 2 degrees of freedom between groups, 87 degrees of freedom within groups and a P-value of 3.5E-03. This P-value indicates that there is a significant difference between the tidal sections for the 2-year-old netting. The average UTS for the low, mid and high tidal sections equal respectively (33.5 ± 1.4) , (31.9 ± 1.8) , and (30.1 ± 6) N. The post hoc test (t-test: two sample assuming unequal variances) resulted in P-values of respectively 0.13, 4.5E-04 and 5.8E-03 for the comparison between the high-mid, mid-low and high-low tidal sections. These P-values indicate that there is a significant difference in average UTS between the mid-low and high-low sections, but not for the high-mid comparison.

The ANOVA-test between tidal sections of the 6-year-old netting resulted in 2 degrees of freedom between groups, 87 degrees of freedom within groups and a P-value of 3.2E-05. This P-value indicates that there is a significant difference between the tidal sections for the 6-year-old netting.

The average UTS for the low, mid and high tidal sections equal respectively (25.4 ± 3.7), (22.3 ± 4.2), and (20.7 ± 3.4) N. The post hoc test (t-test: two sample assuming unequal variances) resulted in P-values of respectively 0.13, $3.5E-03$ and $5.4E-06$ for the comparison between the high-mid, mid-low and high-low tidal sections. These P-values indicate that there is a significant difference in average UTS between the mid-low and high-low sections, but not for the high-mid comparison.

The ANOVA-test between tidal sections of the 15-year-old netting resulted in 2 degrees of freedom between groups, 87 degrees of freedom within groups and didn't indicate a significant difference between tidal sections for this age of netting.



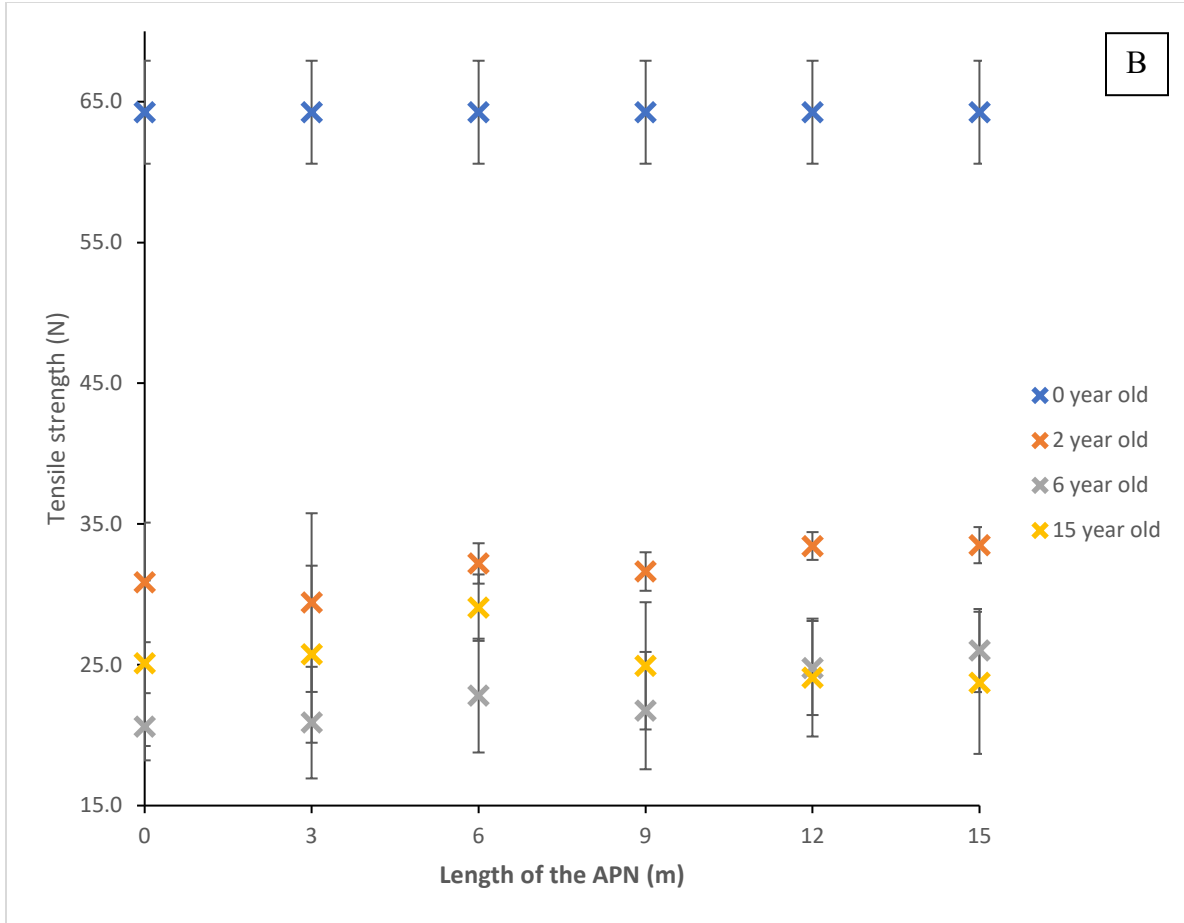


Figure 8. A: Boxplots representing the mean UTS of different lines in each class of APN. B: Mean UTS in each lines of different classes of APN.

3.1.2 Elongation

The results for the tensile test show an average elongation of (12.1 ± 2.2) cm, (11.4 ± 1.8) cm, (9.6 ± 2.1) cm and (6.3 ± 1.9) cm for respectively the 0-, 2-, 6- and 15-year-old netting (Figure 9).

The ANOVA-test between age classes resulted in 3 degrees of freedom between groups, 281 degrees of freedom within groups and a P-value of $9.75E-49$. This indicates that there is a significant difference between the data of the age classes ($P\text{-value} < 0.05$). The F-test indicated that there was no significant difference between the variances of different age classes. A post hoc-test (t-test: two samples assuming unequal variances) was carried out to make a comparison between different classes of APN (Table 2). The P-values indicate a significant difference in average elongation between all age classes, except between the 0- and 2-year-old netting.

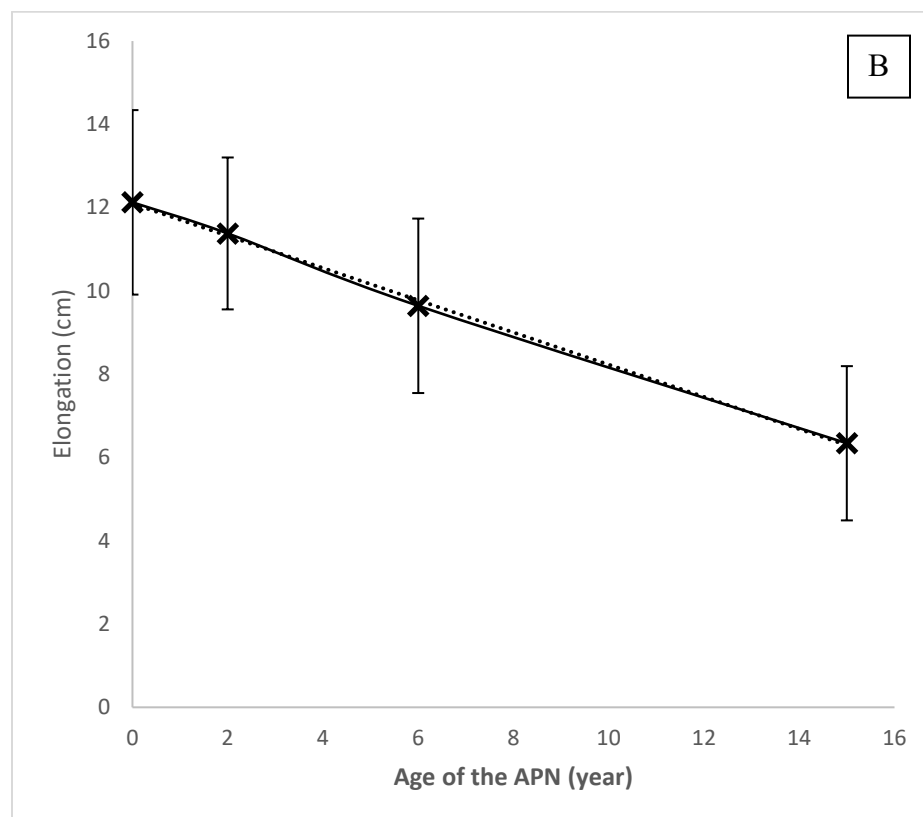
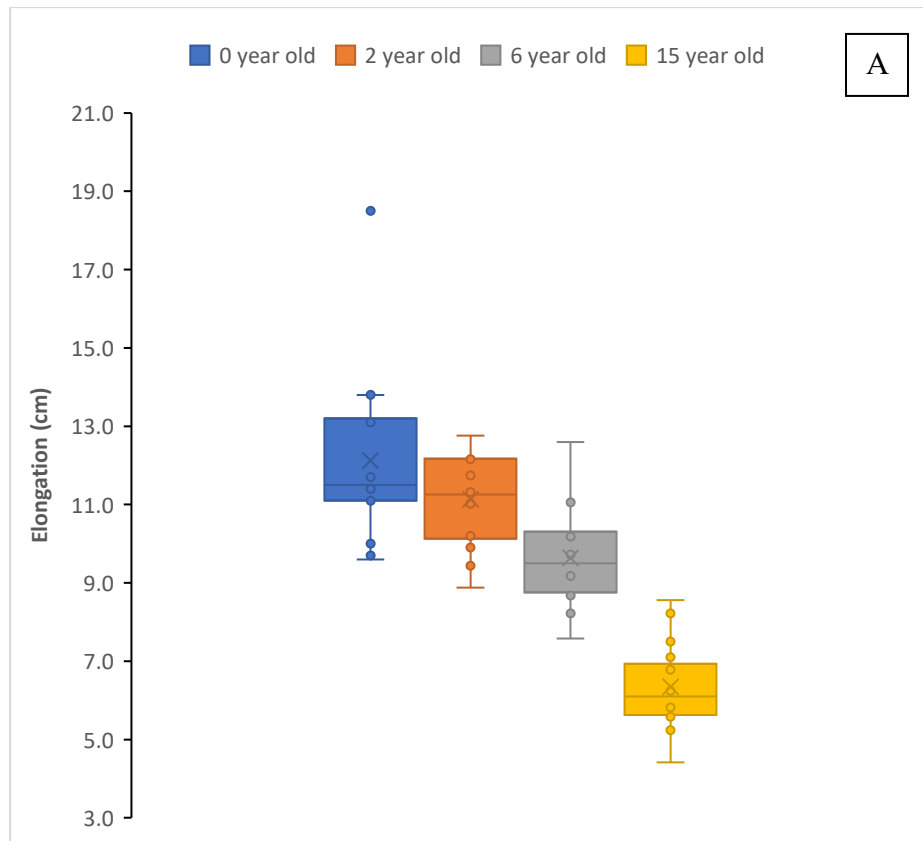
Table 2. Comparison of the elongation between different classes of APN and their corresponding P-values.

Comparison between different classes of APN (year old)	P-value
0-2	0.16
0-6	5.29E-05
0-15	7.96E-19
2-6	1.50E-08
2-15	5.25E-43
6-15	2.23E-22

The ANOVA-test between tidal sections of the 2-year-old netting resulted in two degrees of freedom between groups, 87 degrees of freedom within groups and the P-value indicated that there is no significant difference between tidal sections for this age of netting.

The ANOVA-test between tidal sections of the 6-year-old netting resulted in 2 degrees of freedom between groups, 87 degrees of freedom within groups and a P-value of 0.0139. This P-value indicates that there is a significant difference between the tidal sections for the 6-year-old netting. The average elongation for the low, mid and high tidal sections amounts respectively (10.5 ± 2.0), (9.2 ± 2.0), and (9.2 ± 2.0) cm. The F-test indicated that the variances could be assumed equal for all sections of this netting. The post hoc test (t-test: two sample assuming equal variances) resulted in P-values of respectively 0.9935, 0.01317 and 0.01140 for the comparison between the high-mid, mid-low and high-low tidal section. These P-values indicate that there is a significant difference in average elongation between the mid-low and high-low sections, but not for the high-mid comparison.

The ANOVA-test between tidal sections of the 15-year-old netting resulted in 2 degrees of freedom between groups, 87 degrees of freedom within groups and didn't indicate a significant difference between tidal sections for this age of netting.



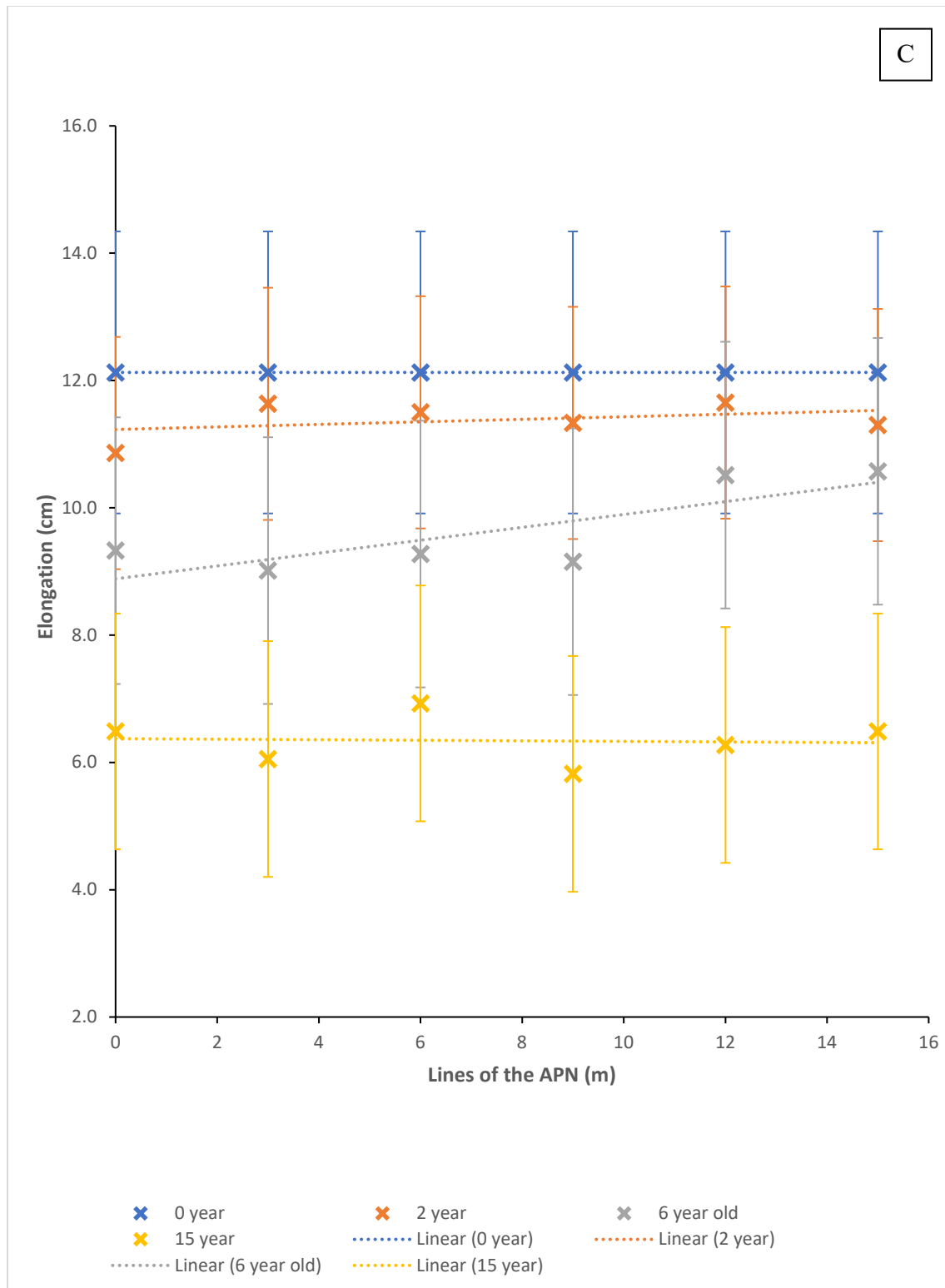


Figure 9. A: Boxplots representing the mean elongation of different lines in each class of APN. B: Average elongation of each net in function of net age. C: Average elongation in function of the lines of each age of netting.

3.2 Dissolved polymers and MPs count

3.2.1 Trial one for BV

The results for the dissolved polymers were not reported as the analysis through BV could not be completed in time. Although, a good indication of mass loss in different lines of different classes of APN could be made, either through loss of MPs or biofouling (Figure 11). The 0-year-old netting (-0.0023 ± 0.0066 g) lost a minimal amount of mass in two of the three lines of the netting which seems more than reasonable as this netting has not been damaged yet by the wear and tear of the ocean. The 2-year-old netting (0.0019 ± 0.0316 g) shows rather similar values, but higher. A clear difference is witnessable between these two younger nettings and the two older nettings. The 6 and 15-year-old netting (respectively 0.0391 ± 0.0062 and 0.0388 ± 0.0045) show too rather similar results and reveal high values of mass loss.

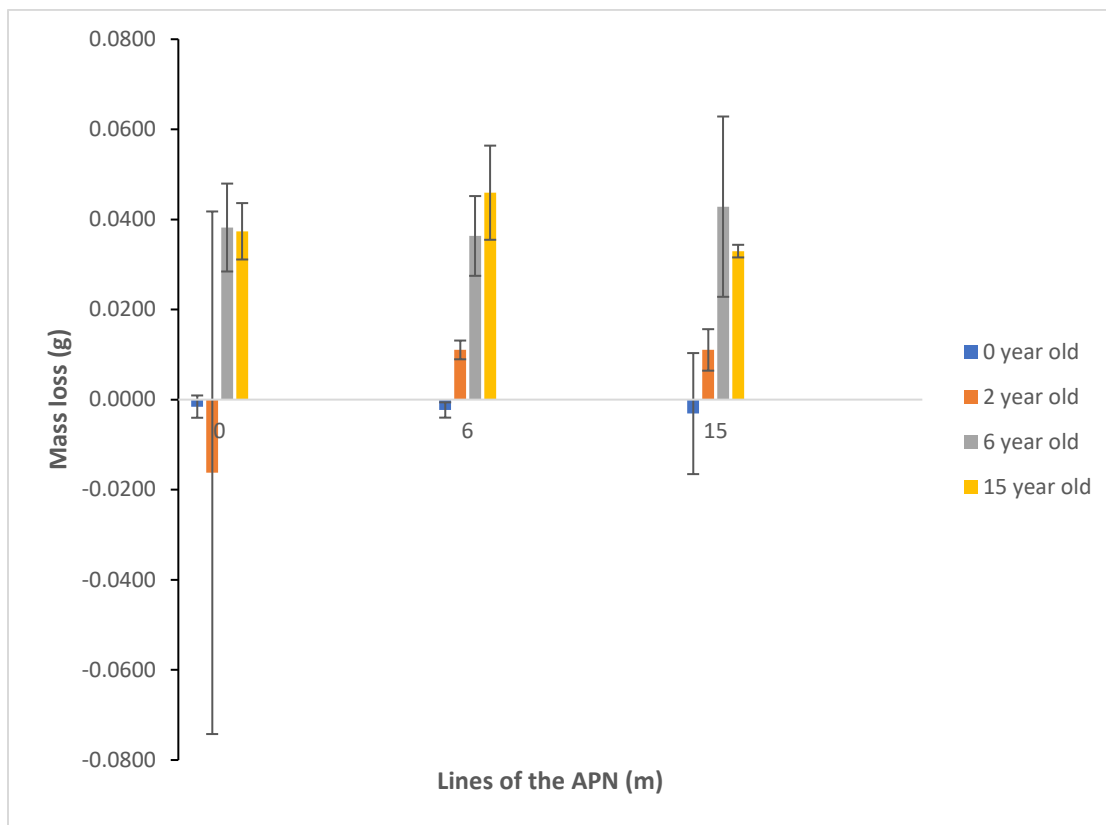


Figure 10. Mass loss at the 0, 6 and 15 m lines from different classes of APN.

3.2.2 Trial two for UBC

The results for the count of MPs are not reported as the analysis through UBC was not done in time.

4 Discussion

4.1 Mechanical properties

4.1.1 Ultimate tensile strength

The mean UTS was expected to decrease with increasing age. The longer the nettings were used, the more they could be degraded by environmental stressors and the easier they would break. The increase in UTS after 6 years of usage is highly irregular. Especially because the 15-year-old netting should be degraded more extensively because it was located at a high exposure area. The sudden increase may be caused by the excessive amounts of biofouling present on the net (Appendix 7.3). A lot of marine life colonized the 15-year-old netting during its lifetime (e.g.: green algae, oysters). The biofouling could have served as a coating that provided extra strength to the netting, resulting in a higher UTS.

The ANOVA and corresponding post hoc tests indicated that there is a significant difference between the average UTS for all ages of netting.

The same ANOVA test was carried out to investigate the difference between tidal sections for each age of netting. The ANOVA test for the 2-year-old netting indicated a significant difference between tidal sections. The corresponding post hoc test indicated a significant difference for the comparison of mid-low and high-low tidal sections, but not for the comparison of the high-mid tidal sections. An increase in mean UTS in function of location on the netting is visible from the mid to low tidal section (9 to 12 m line) (Figure 8B). The same could not be concluded for the high to mid tidal transition because the ANOVA and post hoc test indicated that there is no significant difference between the mean UTS of the high and mid tidal sections.

The ANOVA test for the 6-year-old netting indicated a significant difference between the tidal sections. The corresponding post hoc test indicated a significant difference for the comparison of mid-low and high-low tidal sections, but not for the comparison of the high-mid tidal sections. A decrease in average UTS in function of location on the netting is visible from the mid to low tidal section (9 to 12 m line) (Figure 8B). The same could not be concluded for the high to mid tidal transition because the ANOVA and post hoc test indicated that there is no significant difference between average UTS of the high and mid tidal sections. Note that the results from the 2-year-old netting contradict those of the 6-year-old netting when plotted against location on the netting.

The ANOVA test indicated that there was no significant difference between the tidal sections of the 15-year-old netting. The age and location of the netting could have caused the netting to be degraded to such an extent that differences in degradation across the netting due to orientation in the tidal zone became negligible.

4.1.2 Elongation

A steady decrease in mean elongation is seen the older the netting is (Figure 9A). An almost linear relationship is there between the mean elongation and age class of each netting (Figure 9B), as the curve starts bending slightly upward close to the 15-year point. Although the curve doesn't fit an exact linear model, the deviation is not significant enough to be called exponential. Because degradation rate accelerates with age, the degradation rate was expected to be consistent during the first couple years of usage, and in- or decrease closer to 15 years of usage. However, the 15-year-old netting was located at a high exposure site and was, relatively speaking, degraded more than the 2 and 6-year-old netting at the low exposure area (whether not related to its higher age).

The average elongation could have been higher if the netting was located at a more protected area of the beach (e.g.: the location of the 2 and 6-year-old netting). This would result in an exponential convex decreasing curve. This indicates that the degradation rate slows down with increasing age of the netting.

The ANOVA and post hoc tests between the data from different ages of netting indicated a statistically significant difference in mean elongation between all age classes, except for the comparison between the 0 and 2-year-old netting. Two years of usage didn't degrade these nettings enough to result in a significant difference in mean elongation. The decrease in mean elongation, combined with the statistical ANOVA and post hoc tests, confirms that the elongation drops significantly with increasing age of the nets after two years of usage.

The same ANOVA test was executed to investigate the difference between tidal sections for each age class of netting. The high P-value for the 2-year-old netting indicates that there is no significant difference in degradation across the length of the 2-year-old netting. Two years of usage is most probably not long enough to reach a significant difference in degradation across the netting. Consequently, this data could not be used to evaluate degradation across the net. The low P-value for the 6-year-old netting indicates that there is a significant difference between the tidal sections.

The two-sample t-test (assuming equal variances) indicated a significant difference between the low-mid and low-high tidal sections, but not between the mid-high tidal sections. The biofouling increases significantly between the 3 and 6 m lines, and is similar for the 9, 12 and 15 m lines (Appendix 7.1). This is confirmed by the results for mean elongation in function of the nettings location (Figure 9C), where a clear increase in elongation is visible from mid to low tidal sections or from the 9 to 12 m line. The 9 m line can serve as a benchmark. Nets placed above the 9 m line (in the low tidal area) will degrade significantly slower than net places below the 9 m line (in the mid and high tidal area).

The indifference between the mid (6 and 9 m lines) and high (0 and 3 m lines) tidal sections may indicate that this part of the netting degrades almost evenly. Only the low tidal section (0 and 3 m line) was degraded to a lesser extent because of the lower exposure to solar radiation and higher moisture exposure.

The ANOVA test indicated that there was no significant difference between the tidal sections of the 15-year-old netting. The age and location of the netting could have caused the netting to be degraded to such an extent that differences in degradation across the netting due to orientation in the tidal zone became negligible. Because there is no significant difference between the tidal sections of the 2- and 15-year-old netting, this data could not be used to evaluate degradation across the netting.

4.1.3 Tensile testing machine procedure

Testing the mechanical properties of a certain material is usually carried out with a universal tensile testing machine. Due to limited availability and high acquisition costs, a cheaper and less complex alternative was designed and built for quantification of the mechanical properties. Building a manual tensile testing machine reduced the cost price of this test procedure from a few 1000 to less than 200 CAD. Sadly, the accuracy of the method dropped too.

Conventional tensile testing machines use an extensometer for measuring elongation, an accurate scale for measurements on the UTS, where the samples are stretched with a hydraulic or electromagnetic engine to guarantee a steady stretching speed. In this experiment, the tensile strength was measured with a crane scale with spring sensor (MODERN STEP), which is advertised for its high precision weighing sensors with a weight range of 1 - 300 kg and increments of 0.1 kg or 1 N. During testing, the PE-strings appeared to be weaker than first thought.

The mean elongation of e.g., the 15-year-old netting equals 25.4 N. The scale with 1 N increments could not provide very accurate results on the UTS in the given range. The elongation was measured with a yardstick mounted on the wooden frame, directly behind the string sample. The angle between the camera and the ruler, and the changing position of the clamps and/or string samples resulted certainly in errors. The string samples were stretched with a winch instead of an automatic engine. Because the winch was operated manually, a perfectly even stretching speed could not be obtained. Disruptions in stretching speed can cause deformation in the string samples, causing variations in UTS and elongation results.

Conventional tensile testing produces a stress-strain curve that shows the elastic behavior of the test specimen as a function of time. With a total of 285 single string samples, the given timeframe, the available equipment and budget; it was impossible to produce a similar stress strain curve with the manual tensile testing machine. It was not feasible to fix enough points manually during the tensile test for every subsample. Eventually, the netting was evaluated on purely the UTS and elongation. The other mechanical properties such as flexibility and toughness could not be derived from solely this data.

But overall, the breaking test worked almost perfectly for string samples from the 2, 6 and 15-year-old netting. Most samples experienced breakage in non-nodal sections and didn't break around the clamps, which gives better results. However, string samples from the 0-year-old netting always loosened at the knots without string breakage. The 0-year-old netting has never been used and the nodes were visibly looser in comparison to the other ages of netting (Appendix 7.4). The nodes in other ages of netting seemed to have tightened during usage because of hardening in the (marine) environment. The ocean constantly exerts force on the netting, causing the knots to tighten. And embrittlement as well as biofouling causes more friction between knotted strings, which decreases the smoothness of the polymer surface, and decreases the probability of knots coming loose.

The sampling method was adapted to determine the mechanical properties of the new netting. First, a single string of netting was unknotted which resulted in a 20 cm string sample without nodes. These samples broke with small loads and most often around the clamps. Breakage around to clamps may be caused by damage to the string while fixing it in place and is therefore not desired.

To prevent the netting from breaking around the clamps, the string samples were clamped between a piece of wood in each clamp to increase friction and strengthen the grip. Still, the sample string broke around the clamps. Finally, instead of cutting one straight line, the strings for the 0-year-old netting were cut zigzag (Figure 6). This caused the tensile force to be exerted on the main string in between the clamps instead of many different strings knotted together. This way, the nodes couldn't loosen anymore. Arguably, this method produces irrepresentable results because the pulling force is exerted only on the main string, instead of many different strings tied together, such as the string samples from other age classes of netting.

Discussion can also be made about the data collection method for the elongation measurements. The initial sample length between the clamps wasn't recorded because every sample was clamped in the same position. Given the timeframe, the difference in initial sample length between measurements was not significant enough to include in the report. If reevaluation seems necessary, this can be executed by another researcher soon.

4.2 Dissolved polymers and MPs count

There are some major concerns to be made about the second component of this project. First, the sand used as a degrading agent in the mason jars can contain impurities such as other polymers. These could interfere with the analysis and result in a higher concentration of MPs or any dissolved polymers. To remove most impurities, the sand was rinsed multiple times with tap water until only the bigger fraction (gravel) remained before it was used in the experiment. Second, the salt water used in this experiment is made from tap water. Tap water can also contain contaminants and possibly distort the analysis. Third, it was not possible to remove all biofouling without damaging the surface of the netting. Brushing off the biofouling caused damage to the netting due to heavy friction with the hairs of the brush. Leaving the netting for too long in high concentrations of NaOH solution would cause the OH-radicals to attack the netting too. Fourth, due to the lack of chemical shaking equipment, the jars were shaken by hand. Although the shaking was standardized for each trial, it was impossible to shake every jar the same. The variations in shaking between jars can be justified by mimicking the variations in a marine environment.

Consequently, there was still some fouling present on the 10 by 10 cm subsamples while they were weighed and placed in the mason jars. Some of this fouling was undoubtedly removed during this trial due to friction with water and sand or just dissolution. Biofouling particles were visible floating around in the residual salt water after removing the samples. When the samples were weighed after the trial, that removed biofouling was not measured again. Therefore, the weight loss is not only caused by the loss of polymer material and does not provide an accurate indication for the release of MPs.

Fifth, grown baby kelp was observed on only the 6-year-old netting (Appendix 7.5). This could have affected the measured mass loss and could mean that even more MPs or other sizes were shredded from the netting.

Sixth, the shaking method was done by hand because there was no chemical shaking equipment available, and the budget was limited. The shaking method was standardized but not the same for all the jars because it was done manually. However, the shaking is justified in this experiment because it mimics the degradation of the netting in natural environments to a certain degree.

While rinsing the 10 by 10 cm subsamples (after treatment with the NaOH solution) with demineralized water, soapy bells formed in the meshes of the samples.

This was probably residual NaOH solution on the sample squares. Consequently, the results for this trial were not used to evaluate the mass loss of the netting. The growth and/or loss of biofouling during the trial.

4.3 Overall remarks

Before discussing the results, consideration must be made about the location from which the different classes of netting were collected. The two and 6-year-old netting were collected from a beach area that is only a little exposed to environmental stressors, while the 15-year-old netting was collected from a high exposure area. Most probably, the 15-year-old netting was degraded more extensively than it would have been on the same location as the two- and six-year-old netting.

The pictures of the 50 by 50 cm sample squares (Appendix 7.1) were used to indicate the overall state of the netting based on biofouling and damaged areas. The 0-year-old netting has not been used and obviously showed no breakages or biofouling. Therefore, visualization of the 0-year-old netting was not included here. The samples from the 2-year-old netting show only little biofouling and no damaged areas (Appendix 7.1).

Samples from the 6-year-old netting (Appendix 7.2) show a lot more biofouling in the form of seaweed. Note that the biofouling decreases from the high tidal (0 m) side to the low tidal (15 m) side. The 6-year-old netting also shows the first signs of deterioration, e.g., the right-hand sample from the 12 m line shows a big, damaged area. Overall, there are only a few damaged areas visible. The samples from the 15-year-old netting (Appendix 7.3) show the most extensive biofouling and damage. Pictures of the left and middle sample from the 0 m line got lost during data collection but carried biofouling like other samples from the 0 or 3 m line. The increase in biofouling from the low to high tidal line is even more visible and most samples contain at least one damaged area. Note that the biofouling on each net was caused by different plant species. The 15-year-old netting was fouled with a dense grass like seaweed that held on to a lot of water. Some of this fouling got lost during collection and transportation of the netting.

It's remarkable that the amount of biofouling decreases from the high to low tidal line for the six and 15-year-old netting. The 2-year-old netting wasn't used long enough to allow biofouling to develop to such an extent. The increase in biofouling is most probably a result of the orientation of these nets on the beach.

The nettings were laid out with their short sides (4.40 m) parallel to the waterline. This translates in unequal environmental conditions across the entire length of the netting. The side of the netting closest to the low tidal line was submerged longer during each tidal cycle. Organisms who colonize this side of the netting were more protected against solar radiation and have more nutrients available than organisms growing on the high tidal side. Because photo-degradation is the major degradation mechanism for PE-netting, the side of the netting closest to the low tidal line (15 m line) should be affected the least by solar radiation (low sun exposure due to underwater). And thus, result in a higher tensile strength and elongation, compared to the high tidal line.

As there were some complications with the force gauge, the amount of force that was still visible after breakage on the scale, was also documented and then added up to the previously mentioned breaking force. This gave a more logical view of the results whereas without would give to many obscure results. This was an ongoing complication throughout the whole testing, where at some days a lot of force was witnessable on the force gauge after breakage of the material.

A remark can also be made about each netting as they are made at different times. The production process evolves through time and results in more suitable products for the end users. This results too in small but maybe significant difference of used raw materials and so on, which makes it plausible that even these nettings aren't the same which results in another variable (besides the age class of each netting).

4.4 Prospect

Polymer fishing gear also gets lost a lot in recent years. They are almost immune to the degradation mechanisms and can remain untouched in the marine environment for decades. This will lead to a phenomenon called 'ghost fishing' where abandoned, lost or discarded fishing gear (ALDFG) will catch all kinds of marine wildlife. According to the EU, 20 % of all marine waste in the ocean today comes from ALDFG. More specific, 640 kilo tones of EU ALDFG are found in the ocean every year (Stelfox et al., 2016). Thanks to the natural currents of the ocean, the forming of garbage patches occurs. For example, fishing nets account for 46 % of all the waste in the Great Garbage Patch of the Pacific Ocean which is bounded by the North Pacific Subtropical Gyre (Lebreton et al., 2018).

As polymer fishing gear will not go away any time soon, new and innovative ideas must be implemented to reduce MPs into the (marine) environment soon. For example, B4Plastics are now

developing biodegradable fishing gear with an expiration date. The goal is that the fishing gear will biodegrade in 6 weeks after 2 years of use. When this biodegradable fishing gear meets the water and its micro-organisms, it does not fragment into MPs but natural mineral components like CO_2 and H_2O . Although, some issues must be figured out like keeping track of the different environments where the fishing gear will be used and inspection and reparation services. Another benefit of this idea is the shift from fossil-based materials to biodegradable natural components.

5 Conclusion

A clear difference is seen with the UTS between the 0-year-old netting ($64.3 \pm 3.7 \text{ N}$) and the 2, 6 and 15-year-old nettings who find themselves in the same area (respectively 31.8 ± 3.9 , 22.8 ± 4.2

and 25.4 ± 5.7 N). Here, a statistically significant difference is seen between the 0-2, 0-6, 0-15, 2-6, 2-15 and 6-15-year-old netting (respectively $P = 1.7\text{E-}18$, $3.1\text{E-}21$, $6.2\text{E-}24$, $5.7\text{E-}33$, $2.5\text{E-}15$ and $5.4\text{E-}04$). A statistically significant difference is also seen within the tidal sections of the 2 and 6-year-old netting ($P\text{-value} = 3.5\text{e-}03$ and $3.2\text{E-}05$). In both cases, a statistically significant difference is witnessable between the high-low ($5.8\text{E-}03$ and $5.4\text{E-}06$) and mid-low ($4.5\text{E-}04$ and $3.5\text{E-}03$) sections of the APN. There is no difference in the high-mid sections of each APN.

A significant reduction in average elongation is observed after two years of usage (0-year-old: 12.1 ± 2.2 , 2-year-old: 11.4 ± 1.8 , 6-year-old: 9.6 ± 2.1 and 15-year-old: 6.3 ± 1.9 cm). The biofouling and elongation results (six-year-old netting) strongly indicate that netting used close to low tidal line degrades slower than netting used closer to high tidal line in the tidal zone. Fifteen years of usage degrades the netting to such an extent that differences in degradation across the netting caused by tidal movements become negligible. Netting should be replaced after 15 years of usage.

Second, these nettings were tested for leaching dissolved polymers and microplastic particles to their environment. Unfortunately, the results are not reported yet as the analysis of these samples was not done in time, although a good indication of mass loss can be made (whether present from the biofouling). The 0 and 2-year-old netting (respectively -0.0023 ± 0.0066 and 0.0019 ± 0.0316 g) show different results in comparison to the 6 and 15-year-old netting (respectively 0.0391 ± 0.0062 and 0.0388 ± 0.0045 g).

We can conclude that 15 years of usage degrades the netting too extensively. Removing the APN after 10 years of usage would be more than reasonable. It is advised to use APN closer to the low tidal line, this may increase the lifetime of the netting.

As the baseline of this project is set, prospects can also be considered. Testing various kinds of materials instead of the APN is a logical next step. Shellfish aquaculture is a big industry and therefore uses a lot of different materials like e.g. buoys and trays. A longer period is preferred as it will take some time until the plastic material releases any MPs (and/or NPs). Setting up experiments for 1, 2, 4, 6 and/or 12 months is the next step to be taken to map out the release of MPs in a wider view of time.

A difference can then also be seen within the different seasons where the summer involves more photo-degradation, and the winter more mechanical degradation. Adding up the volume and the

real-life conditions is also a crucial factor to think about along the way. As there is a big gap witnessable with the UTS between the 0 and 2-year-old netting, testing a 1-year-old netting would give a good view of where it exactly locates itself in that gap.

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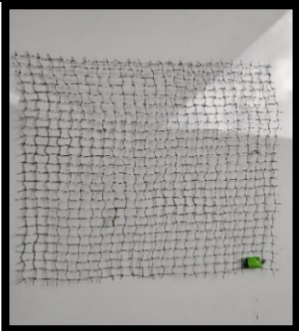
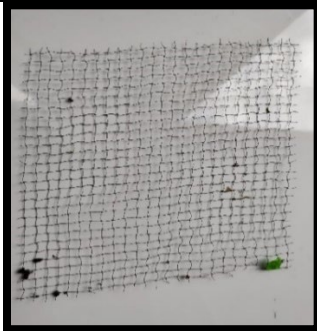
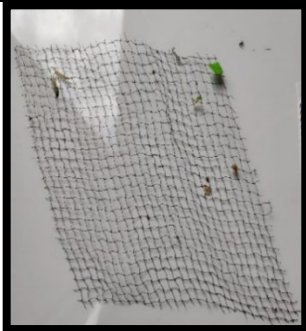
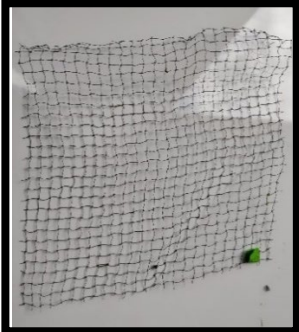
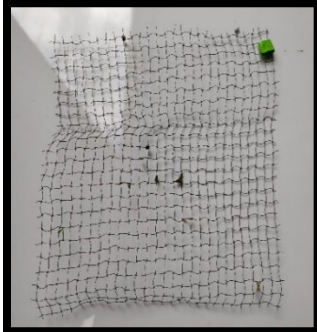
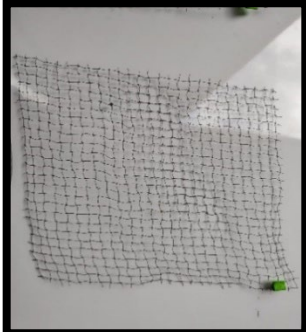
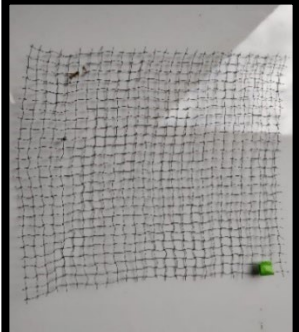
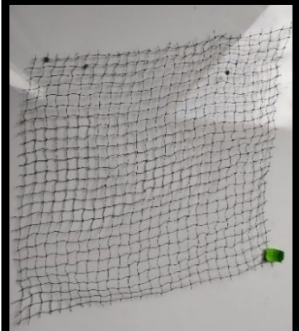
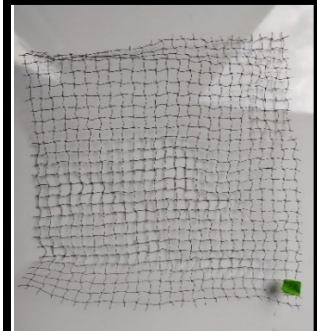
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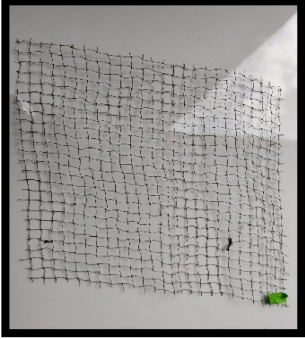
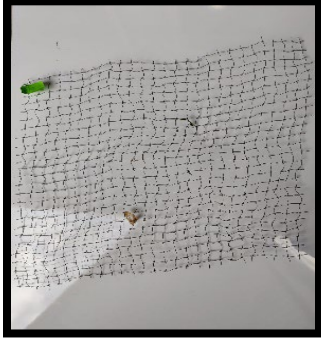
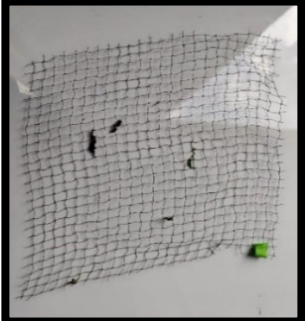
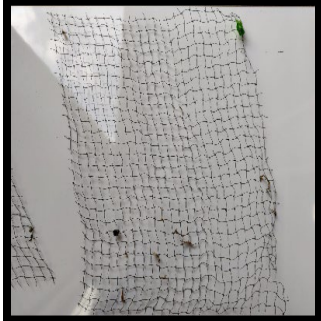
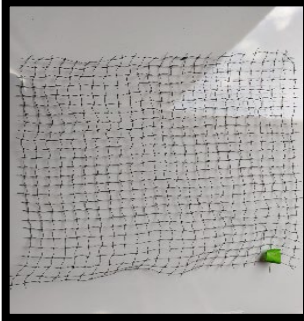
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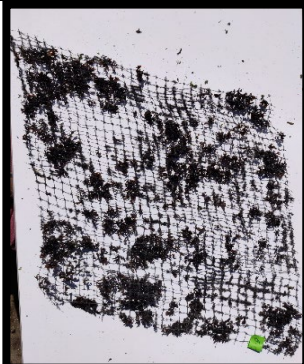
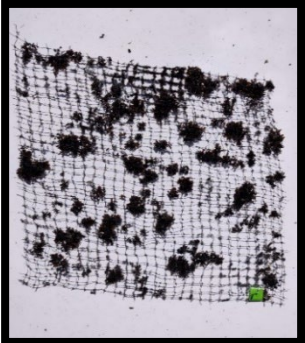
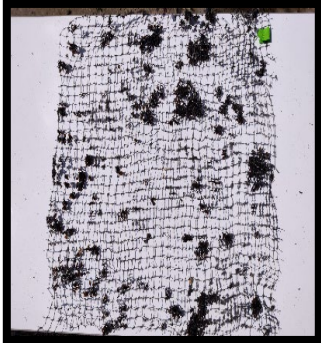
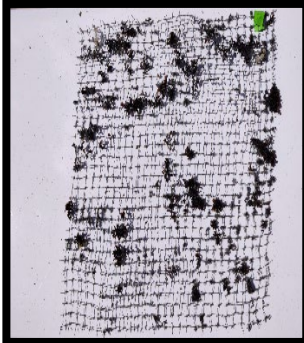
7 Appendices

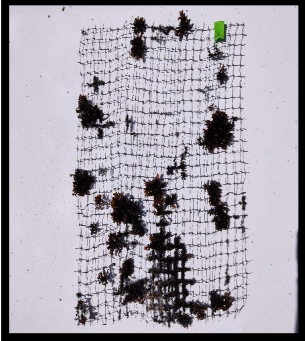
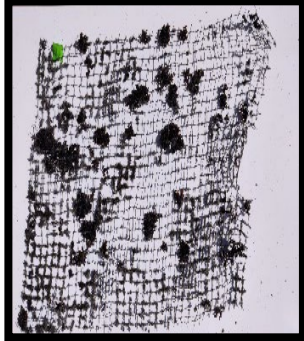
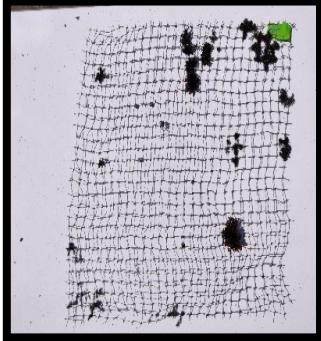
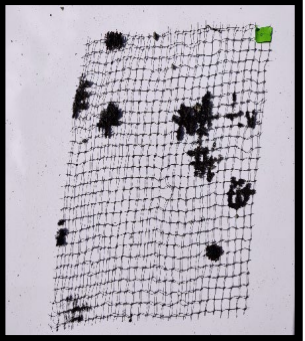
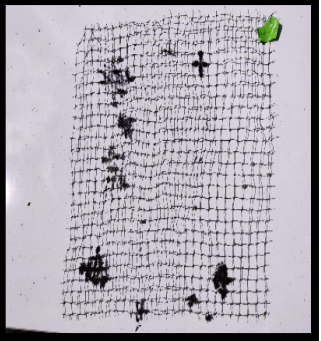
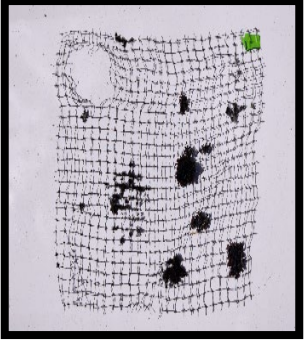
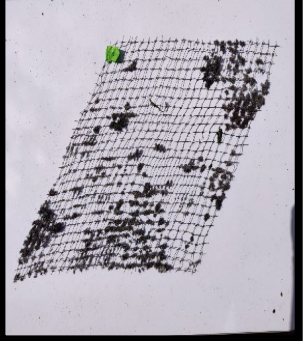
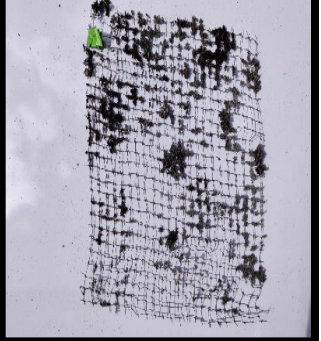
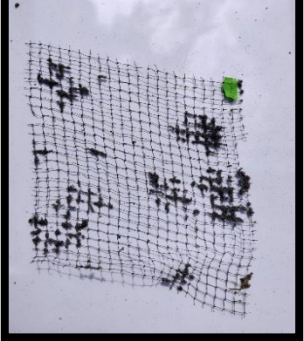
7.1 50 by 50 samples cut out of each APN.

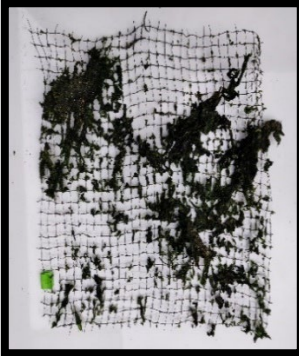
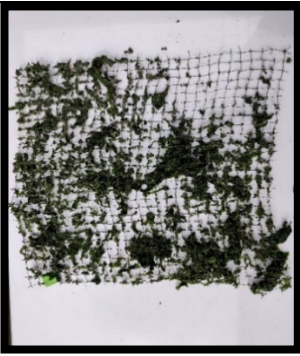
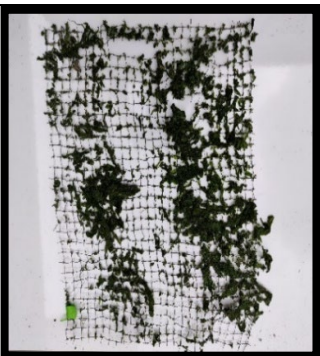
2-year-old	Left	Middle	Right
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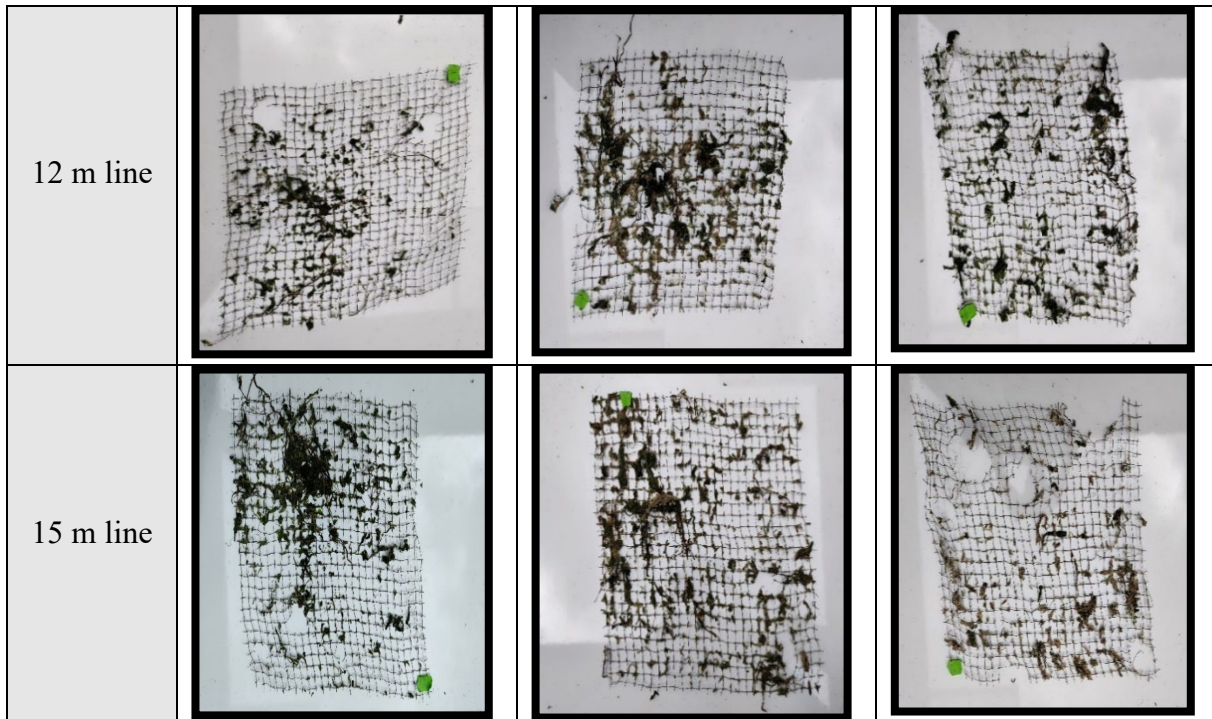
0 m line			
3 m line			
6 m line			
9 m line			

12 m line			
15 m line			

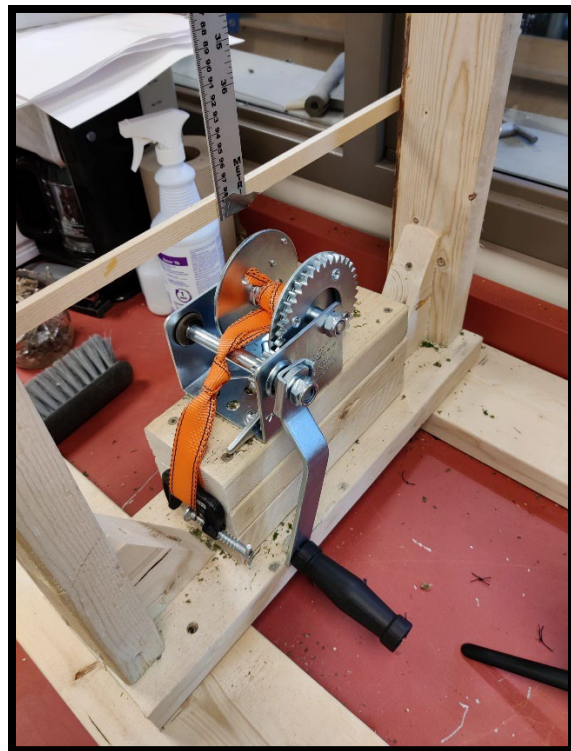
6-year-old	Left	Middle	right
0 m line	/	/	
3 m line			

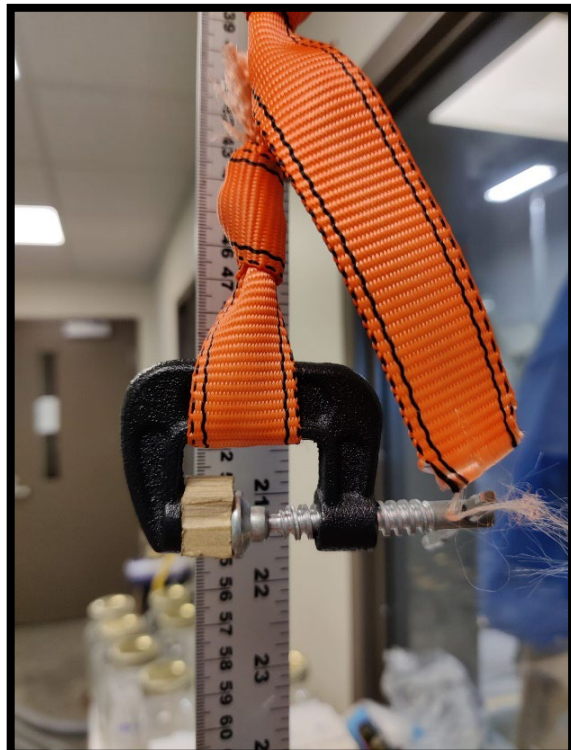
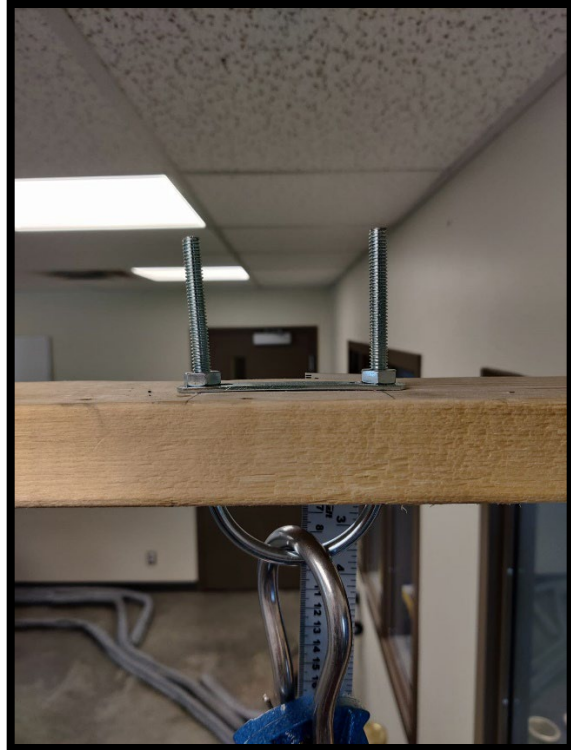
6 m line			
9 m line			
12 m line			
15 m line			

15-year-old	Left	Middle	Right
0 m line			
3 m line			
6 m line			
9 m line			

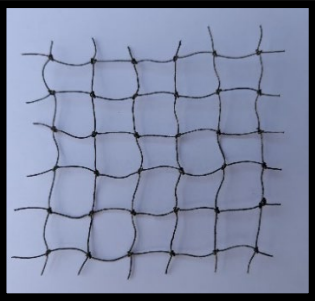


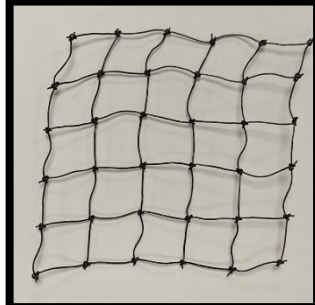
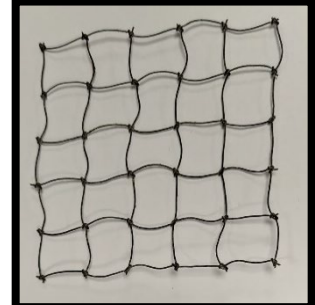
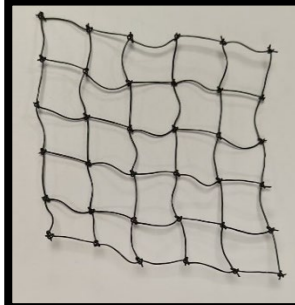
7.2 Extra photos of the in house build tensile testing device.

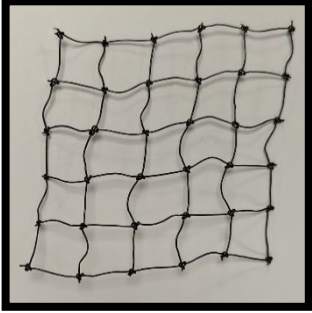
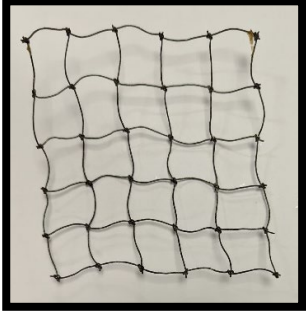




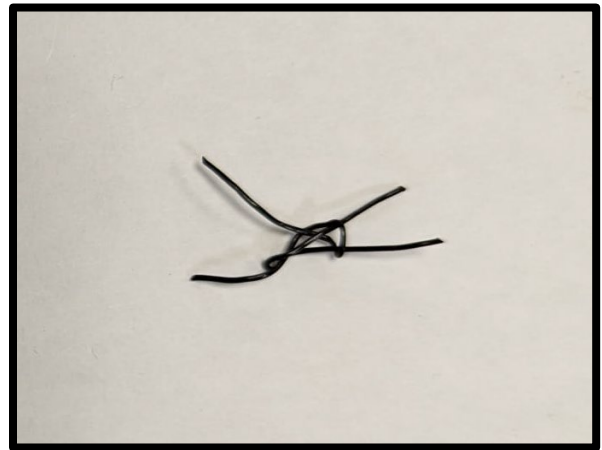
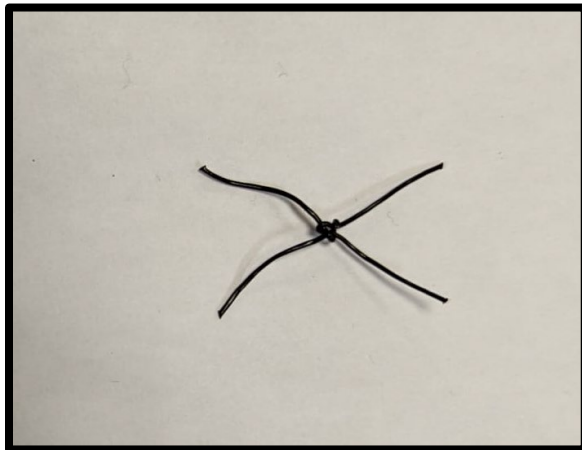
7.3 10 by 10 subsamples cut out of the 50 by 50 samples.

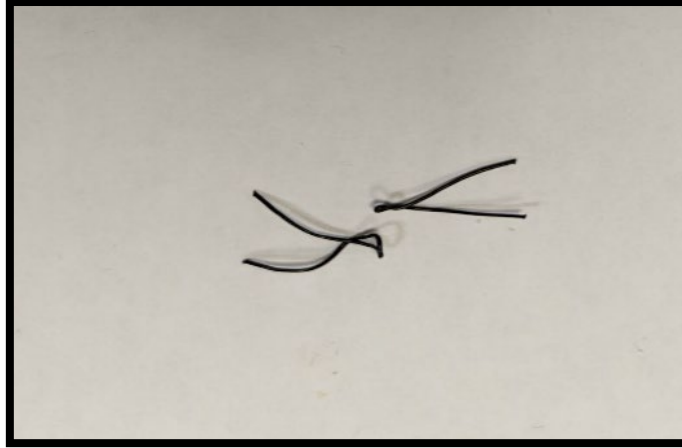
Dissolved polymers	0 m line	6 m line	15 m line
2-year-old			
6-year-old			
15-year-old			

MPs count	0 m line	6 m line	15 m line
0-year-old			

2-year-old			
6-year-old			
15-year-old			

7.4 The disconnecting ways of the nodes with the 0-year-old netting.





7.5 Grown baby kelp on the 6-year-old netting after the dissolved polymers experiment.

