Water Quality for Fisheries

An Assessment of Water Quality Concerns

Introduction

The purpose of the Water Quality for Fisheries (WQ4F) Project is to identify and address the impacts of water quality on the North Carolina fisheries.

Part of this process includes researching and assessing what is currently being done to address water quality issues that impact fisheries. The assessment part of this project will include what is being done to address sources of pollution from all areas of NC (including those outside of the coastal area).

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Table of Contents:

Priorities Identified by Coastal North Carolina Fishermen:

Agriculture and Factory Farm Runoff
Stormwater Runoff from Roads, Highways, and Parking Lots
Industrial Pollutants
Plastic Pollution
Municipal Wastewater Treatment Plants and Septic Tanks

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Plastic Pollution

Introduction

Plastic pollution has received a significant amount of media attention the last few years, but there is still a dire need to create regulatory policies and effective infrastructure in order to mitigate the harmful impacts of plastics on aquatic ecosystems. Each year a quantity between 4.8 and 12.7 million tons of plastic ends up in the ocean worldwide (Michelson, 2021). Unfortunately, only 10% of plastics produced globally actually goes through the recycling process while the rest enters the environment, sits in landfills, or burns (Michelson, 2021). In fact, the United States incinerates six-fold more plastic than the amount recycled.

The plastics entering the oceans break down into microfibers that fish and birds then consume. Due to plastic ingestion and entanglement, greater than 1,200 species are impacted by waste pollution. There are two main concerns with plastic pollution for aquatic life: the physical harm due to entanglement and the poisoning of fish and wildlife after ingestion. In addition to directly harming fish through entanglement and ingestion, the use of plastics also harms wildlife due to their contribution to climate change because they are made from the fossil fuel, petroleum.

One effect of entanglement includes injured or lost limbs or fins which impacts the individual's ability to swim, catch prey, and reproduce. Additionally, accidental ingestion of plastic is common among marine species and can affect the food chain when the prey has already ingested debris. The consequences of ingesting plastic include throat and digestive blockages, gut damage, and malnutrition or starvation. Plastic consumption may also cause implications to marine life’s nutrition, development, and immune system. Also, these products can contain harmful chemicals that are toxic when ingested.

Plastics are major contributors to municipal solid waste (MSW) with containers and packaging materials having the greatest plastic tonnage of 82.2 million tons (28.1% of total generation) according to the EPA (EPA's Containers and Packaging: Product-Specific Data, 2021). This classification of plastics includes bags, sacks, and wraps; polyethylene terephthalate (PET) bottles and jars; high-density polyethylene (HDPE) natural bottles; and other containers and packaging. Plastics can be found in durable products such as appliances, furniture, casings of batteries, and more. Some nondurable products include disposable diapers, trash bags, cups, utensils, medical devices, and shower curtains. Food containers are composed of clear or foamed polystyrene, trash bags are made of HDPE or low-density polyethylene (LDPE), and resins make up other nondurable goods.

In addition to the noticeable pieces of plastic waste we often see, microplastics are a common plastic pollutant entering bodies of water. Microplastics are tiny pieces of plastic that are used in pre-production plastic pellets, microbeads, and microfibers. These materials are used in cosmetics, microfibers from polyester, and production for larger plastic products, and they can absorb harmful pollutants and release them in the ocean like pesticides, dyes, and flame retardants (National Oceanic and Atmospheric Administration, US Department of Commerce, 2018). They also can be pieces of plastic that have broken down to less than 5 mm in diameter.

There are two main sources of plastics: land-based sources and ocean-based sources. The National Marine Debris Monitoring Program with NOAA, completed a five-year national research project focused on monitoring debris at beaches. They found 49% of marine debris found was land-based source items, 18% were ocean-based source items, and 33% were shoreline debris and could be a result of land-based or ocean-based littering (National Oceanic and Atmospheric Administration's Programmatic Environmental Assessment, 2013). A large proportion of plastics reach coastal waters through stormwater drains, creeks, bridges, beach tourism, and recreational boating. Microplastic pollution in coastal waters is a result of runoff carrying material and the breakdown of meso- and macroplastics in the water. Plastics are easily degradable in water due to biodegradation;

photodegradation; thermooxidative degradation, slow oxidative breakdown; thermal degradation; and hydrolysis (Andrady, 2011). Pollution increases with the occurrence of natural events such as storm surges, hurricanes, flooding, and high winds (National Oceanic and Atmospheric Administration's Programmatic Environmental Assessment, 2013).

Plastics can increase toxicity in water and marine life due to the presence of toxic additives in the product that may leach out when ingested. During the degradation of plastics, specifically burning, harmful toxins such as styrene and other aromatics can be generated. Microplastics absorb toxins to their surfaces which allows for biomagnification of harmful chemicals in the marine environment (Andrady, 2011). For example, toxic persistent organic pollutants (POPs) present in the ocean are absorbed and concentrated in microplastics making them bioavailable to individuals who consume the filaments.

Plastics act as a means of transport for toxic chemicals and plastics generally contain their own hazardous chemicals added during manufacturing (Campanale, 2020). Plastic molecules are able to take up toxic molecules from the environment and release them in animals after being ingested. Plastics are able to remove iron molecules from an organism and replace it with lead. Also, plastics such as polystyrene and polyvyropuride contain polymers such as plasticizers which are some of the greatest water polluters. Plastic is found everywhere from fences, house siding, and rugs and when these products are exposed to rain, these dangerous molecules are washed into nearby bodies of water.

Plastics are sources of endocrine-disrupting chemicals found in aquatic and marine ecosystems. They can cause severe reproductive issues in female and male organisms such as infertility and feminizing male fish (Harvey, 2019). Similarly, they can take up harmful chemicals such as synthetic hormones found in birth control pills and cause sex morphism in male fish (Harvey, 2019).

Infrastructure Assessment

Current Actions:

Type of Infrastructure	Water Quality Impacts	Lead Organization
Plastic Waste Management: Composting, Recycling, and Combustion with Energy Recovery	• Reduces plastic pollution from disposal sites • Decreases greenhouse emissions • Limits risk of chemicals affecting fish population	Environmental Protection Agency (Southeast Regional Office) 800.241.1754
Pyrolysis	• Contains plastic waste, decreases the risk of it entering bodies of water • Produces energy	Recycle for Change 510.932.3839
Biodegradable and Compostable Plastic	• Increases rate of degradation, limiting the quantity leaving facilities and entering bodies of water • Decreases release of toxic chemicals into the environment	Environmental Protection Agency (Southeast Regional Office) 800.241.1754
Sampling Technologies for Macroplastics: Visible Counts and Remote Sensing	• Determines levels of plastic pollution and identifies areas of concern • Locates sources of plastic pollution	Cooperation of Research Infrastructures (COOP+) Various Research Institutions

Current practices utilized to manage plastic waste include incineration, landfill use, recycling, composting, and combustion with energy recovery. The EPA is responsible for assessing the effectiveness of these processes. They found that there were 35.7 million tons of plastic production in 2018 and 12.2% of MSW generation was plastics (Environmental Protection Agency, 2021). The American Chemistry Council along with the National Association for PET Container Resources provides data regarding the recycling of plastic. They found that 8.7% of plastics in the US were recycled in 2018. However, 29.1% of PET bottles and jars and 29.3% of HDPE natural bottles were recycled that year. Over 15% of plastics were incinerated with energy recovery and over 75% of plastics were landfilled (Environmental Protection Agency, 2021).

Companies and industries are developing innovative ways to handle plastic waste through new infrastructure. Dow works with other organizations to develop the "Recycle for Change" project. The program is made up of experts that assist communities in developing a work model for cooperatives. One technology utilized by Dow and its partners includes pyrolysis which allows plastics that are generally difficult to recycle to be used as fuel (Parletta, 2019).

With the attempt to reduce plastic pollution, industries have developed biodegradable and compostable plastics that microorganisms can degrade. This assists with preventing future waste, but there is an urgent need to address the plastic waste already present in the environment. The current methods of waste management are destructive to the environment including the incineration of plastic which emits toxic chemicals into the atmosphere. Similarly, the use of landfills releases greenhouse gases and leeches contaminants into the environment. Present recycling methods are significantly inadequate as we have seen in the United States with only 9% of all recyclable plastics being recycled (Sheth, et al., 2019).

Scientists utilize cage-like structures to capture macroplastics in bodies of water, visual counts, and remote sensing to define an amount of visible plastics (Conchubhair, et al.,

2019). However, sampling for microplastics is more difficult. A common sampling process includes the collection of water samples from the field, filtration, separation, and finally quantification in a lab setting (NOAA, 2016).

Recommended Future Actions:

Type of Infrastructure	Water Quality Impacts
Restructuring Manufacturing Process of Plastics: Changing Chemical Composition and Product Design	• Decreases excess plastic production and contamination • Increases chemical stability of plastics and reduces toxin levels • Reduces entanglement and ingestion of plastics for marine life
Microplastic Filtration Technologies	• Decreases microplastic contamination • Reduces toxic impacts on aquatic life
Updated Wastewater Treatment and Waste Management Infrastructure	• Filters microplastics from wastewater • Reduces the amount of plastics exiting waste facilities and entering the environment
Bioengineering Technologies: Plastic-Degrading Organisms	• Degrades plastics and reduces the amount of plastics entering bodies of water • Decreases leaching of chemicals into the environment
Improving Plastic Disposal Bins (Recycling Bins)	• Increases amount of plastic recycled • Decreases plastic pollution resulting from litter

Develop Marine-based Research Infrastructures (RIs)	• Allows for microplastic contamination assessment and identification of problem areas

To begin, addressing the over-production of plastic is an essential step in reducing the pollution of coastal waters. Some ways to combat the excessive manufacturing of plastic includes restructuring plastic chemistry, product design, recycling techniques, and consumer habits (Parker, 2018). Changing the toxic chemical makeup of plastics will allow for safer chemical composition of materials and reduce the amount of dangerous waste entering landfills and the environment. Developing alternatives to plastic is necessary to eliminate plastic pollution because plastic can only be recycled once, meaning it eventually ends up in a landfill or the environment.

Microplastics easily enter bodies of water due to their prevalence in a significant amount of products as well as their small size. Due to the lack of technology available to filter microplastics from wastewater, hundreds of thousands of clothing fibers are released in one load of laundry (Hallas, et al., 2018). Strategies to reduce the amount of microplastics leaving individual homes include the installation of laundry and sink filters and the overall improvement of wastewater treatment plants.

In the future, there is a need for updated wastewater treatment infrastructure that has the ability to filter out the microplastics currently polluting waters worldwide. Urgent development of successful waste collection, management, and recycling processes proves to be necessary in order to prevent plastic disposal into the environment. Improving waste management technologies and avoiding incineration as a means to get rid of waste will greatly aid in reducing the amount of toxins entering the environment (Gallo, et al., 2018). In order to increase the amount of material recycled requires an improvement of the sorting process for plastic waste. Currently, there are many difficulties associated with sorting out the various types of plastics received by facilities and removing materials that are contaminated by non-recyclable waste.

Research is currently underway to identify other means to break down plastic waste without harming the environment. Recently, an investigation of fungi and bacteria that have enzymes with the ability to degrade the polymers in plastic waste has been initiated. However, scientists have only found a few populations of these species in India and Japan. Therefore, we need more research to locate potential plastic-degrading organisms and develop the infrastructure to utilize these species. This method and other bioengineering technologies as a plastic waste reduction strategy could greatly reduce the harmful impacts of microplastics and macroplastics on aquatic ecosystems.

In order to encourage proper plastic disposal and recycling in public places at the coast, we can provide appropriate waste disposal bins to the public that store waste until collection can pickup the trash has been successful in limiting the amount of litter on beaches and coastal communities. Also, adding recycling bins to sites with trash bins will assist with storage and proper disposal of plastics and other recyclables (Hallas, et al., 2018).

One technology utilized in many European research institutions, marine-based Research Infrastructure (RI), assesses different environmental factors, but they do not evaluate plastics in the water column (Conchubhair, et al., 2019). Scientists have been researching technologies that can be utilized to assess plastic levels. Researchers can use remote sensing to evaluate the amount of plastics in water, but they do not have the technology to assess microplastics on site due to their small size (Conchubhair, et al., 2019). Moving forward, developing a technology to precisely evaluate microplastic contamination in water samples is essential.

Policy and Enforcement Assessment

Current Actions:

Type of Policy	Water Quality Impacts	Lead Organization

The UNEA Resolutions	• Addresses marine litter, microplastic, and waste management issues • Reduces plastic consumption and pollution	United Nations Environment Assembly
Marine Debris Research, Prevention, and Reduction Act	• Identifies sources of marine debris and reduces contributions to plastic pollution • Protects marine habitat	National Oceanic and Atmospheric Administration (Marine Debris Program) marinedebris.web@noaa.gov
Microbead-Free Waters Act	• Reduces micro-bead contamination in aquatic ecosystems	US Food and Drug Administration 888.INFO.FDA (1-888.463.6332)
Act to Prevent Pollution from Ships	• Limits ship emissions and pollution of marine waters	Environmental Protection Agency (Southeast Regional Office) 800.241.1754

North Carolina Littering Policies	• Reduce debris from entering coastal waters • Monitor plastic pollution	North Carolina Division of Marine Fisheries 877.623.6748
NC Managing Environmental Waste Act of 2021	• Decreases plastic waste from food packaging • Reduces plastic pollution from facilities	Agriculture and Natural and Economic Resources Committee 919.715.3021

Some policies that establish plastic pollution regulation globally include the international UNEA Resolutions used to address marine litter, microplastics, and waste management; the G20 countries', which includes the United States, implementation of actions to reduce marine plastic litter; and the Basel Convention's legislative objectives to address plastic waste (Plastics Policy Inventory, 2020). Additionally, the Convention on Migratory Species has developed resolutions to address environmental issues associated with marine debris.

There are policies developed to decrease debris and waste pollution. For example, the Marine Debris Research, Prevention, and Reduction Act aims to identify sources of debris, assess, reduce, and prevent marine debris from negatively affecting the marine environment (Hallas, et al., 2018). The act is not specific to plastic pollution, but includes these materials in the reduction efforts.

The International Fisheries Regulations, aiming to regulate fisheries management within and outside of US jurisdictions; the Microbead-Free Waters Act, prohibiting the production, packaging, and distribution of rinse-off cosmetics that contain plastic microbeads; and the Act to Prevent Pollution from Ships (Plastics Policy Inventory, 2020). This act includes an

international treaty that is enforced by the EPA with severe penalties for ships that do not comply.

The state of North Carolina has implemented policies in order to manage the release of debris into bodies of water. For example, there are laws stating that a watercraft or vehicle must have appropriately secured any load they are carrying (Hallas, et al., 2018). The North Carolina Division of Marine Fisheries is responsible for regulating littering policies within the state (Hallas, et al., 2018). However, the policies often lack a focus on plastic pollution.

In 2009, the North Carolina General Assembly banned plastic bags on the Outer Banks which mandated establishments replace disposable plastics with paper bags. Unfortunately, in 2017 the bill was repealed and some stores resorted to plastic bag usage again.

In April of 2021, the NC House passed the NC Managing Environmental Waste Act of 2021 which aims to address plastic waste issues by increasing cities and counties funding for plastic reduction programs, developing a pilot program to reduce plastic waste at food service facilities ran by the state, and mandate the Agriculture and Natural and Economic Resources Committee to research plastic pollution (National Caucus of Environmental Legislators, 2021). The bill is still being reviewed by the NC Senate. In May of 2021, a bill enacting a ban on single-use and non-recyclable products was proposed in the North Carolina General Assembly. There have not been any votes or advancements with the potential legislation (National Caucus of Environmental Legislators, 2021).

There has been progress in managing litter in coastal waters. At the national level, the NOAA has developed a Marine Debris Program under the Marine Debris Act that funds marine debris management and research across the country. Another important governmental program at the state level includes the North Carolina Monofilament Recycling Program (NCMRP) which encourages the collection of monofilament from recycling bins along the state's coast and recycles the material (Hallas, et al., 2018).

Another contributor to plastic pollution in the oceans and coastal rivers includes derelict fishing materials such as monofilament fishing line; plastic mesh, ropes, and bags from shellfish farms. The state receives funding from NOAA and the North Carolina Sea Grant to implement the North Carolina Coastal Federation's Lost Fishing Gear Recovery Project. Fishermen are funded to recover derelict crab pots and fishing gear (Hallas, et al., 2018).

Recommended Future Actions:

Type of Policy	Water Quality Impacts
Plastic Bag, Styrofoam, Single-Use Plastic, and Straw Bans	• Eliminates plastic contamination from these sources • Protects fish populations and habitat
Plastic Bag Tax	• Reduces plastic bag usage and pollution • Decreases risk of entanglement, ingestion, and poisoning for aquatic life
Extended Producer Responsibility Policies	• Increases recycling and composting of plastic products, reducing the amount of plastic entering water systems • Decreases implications of plastic pollution on fisheries
Implementation of a State-Wide Plastic Pollution Program	• Encourages collaboration among municipalities, greatly reducing plastic pollution and consumption • Holds polluters responsible • Establishes water quality standards for plastic pollutants
Government Funded Debris Clean-Up Initiatives	• Improves beaches and rivers conditions through clean-ups

	• Protects aquatic habitat and populations
International Treaty Setting Measurable Plastic Reduction Targets	• Holds countries accountable for plastic pollution • Reduces plastic pollution in the oceans and protect marine life
Microplastic Regulatory Policy	• Decreases microplastic pollution in the nation's bodies of waters • Protects aquatic life from entanglement, ingestion, and poisoning due to plastic pollution

Several states have passed legislation to assist in regulating plastic production, consumption, and disposal. Currently, 12 states have passed legislation that reduces single-use plastic production and 10 states have legislation in progress (Environment America, 2019). However, North Carolina has not passed more stringent plastic regulations. There are several policy options currently being utilized that could assist in decreasing plastic pollution and increasing recycling practices. For example, bans on plastic bags, polystyrene (Styrofoam), single-use plastic, and straws are already being implemented by some US states (National Caucus of Environmental Legislators, 2021). Roanoke, Virginia passed a 5-cent tax on plastic bags that allocates the revenue to environmental efforts, waste reduction programs, pollution mitigation initiatives, and SNAP recipients (Mahoney, 2021).

Extended producer responsibility policies require producers to make single-use products recyclable or compostable. State commissions and councils can assist in completing research and defining the severity of plastic pollutants in the environment, create management recommendations, and develop policy to address these issues (National Caucus of Environmental Legislators, 2021). Another common way states have attempted to reduce plastic consumption is passing legislation that supports the use of reusable bottles in business establishments and installing beverage container deposit systems (or refill stations).

One limitation to the management of marine debris on the coast includes the lack of collaboration between municipalities (Hallas, et al., 2018). One way to remedy this problem would be to implement coordination by the state as a whole. Having a state-wide plastic pollution program could assist in reducing the contamination.

Another option in place of developing a new pollution-control program for plastics is to incorporate plastic reduction efforts into existing policies such as the Stormwater Program. The program could take on plastic and debris pollution, identify sources, and hold polluters accountable. The NCDEQ could increase the enforcement of littering laws and develop water quality standards for plastic pollutants. Additionally, it is important for the EPA to establish criteria for plastic pollution levels in order for states to enforce these programs.

Increasing government funding for coastal cleanups could greatly assist in reducing the amount of plastics carried by runoff to the estuaries and ocean. The Department of Transportation allocates millions of dollars per year to fund litter pickup and cleanup work. However, even $19 million spent for trash pickup does not provide enough funding to clean 40% of primary roads and 90% of secondary roads in the state (Hallas, et al., 2018).

Establishing a binding, international treaty that sets specific and measurable targets for plastic reduction efforts could greatly assist in reducing plastic pollution in the ocean. Due to plastics' ability to float and travel long distances easily, it is important to address contamination sources globally to reduce marine plastic.

Finally, creating policies that aim to regulate microplastic production and pollution is essential in protecting aquatic life. With microplastics being a relatively recent area of study, there has not been political action relative to its management in marine and freshwaters. As scientists' research confirms the significant harmful effects of microplastics on marine mammals and fish, the next step would be to establish standards and criteria for microplastics.

Research Assessment

Current Actions:

Type of Research	Water Quality Impacts	Lead Organization
First Global Analysis of Plastic Pollution	• Quantifies the amount of plastic in the ocean • Identifies greatest sources of pollution, assisting in the mitigation of their contamination	
Assessment of Plastic Pollution Levels in North Carolina	• Provides data that can be utilized in the development of regulatory actions • Reduces plastic pollution from identified sources	North Carolina Marine Debris Symposium LisaR@coastalcarolinariverwatch.org National Oceanic and Atmospheric Administration (NOAA) Marine Debris Program sarah.latshaw@noaa.gov North Carolina Coastal Federation 252.393.8185 Duke University (Plastic Pollution Working Group) plastics@duke.edu

Research on the Impacts of Plastic Ingestion on Aquatic Life	• Determines the extent of effects of plastic ingestion on aquatic life and methods to mitigate the occurrence • Provides estimates for percentage of aquatic life ingesting plastics	North Carolina Marine Mammal Stranding Network https://www.marinemammalsnccnc.com/information-and-resources.html Duke University Marine Laboratory 252.504.7503
Evaluation of Toxicity of Plastics and Related Impacts	• Limits the amount of toxic chemicals leaching into the environment • Provides information about the implications of chemicals on aquatic life	Duke University: Various Scientists Plastic Ocean Project Bonnie@plasticoceanproject.org
Studies Focused on Heavy Metal Contamination	• Provides data regarding the utilization of heavy metals in plastics and their effects on aquatic species	Environmental Protection Agency (Southeast Regional Office) 800.241.1754
Analyzing Plastics' Effects on Local Water Temperatures	• Assesses the extent of influence plastic has on coastal waters • Analyzes the impacts of warmer temperatures on aquatic life	University of Tasmania's Institute for Marine and Antarctic Studies

Studies on the Trophic Transfer of Plastics and Long-Term Effects on Aquatic Species	• Increases our understanding of the transfer of plastic toxins from prey to predator • Develops knowledge base to assist in protecting fish species	Bonnie Monteleone 910.616.6766
Generating Estimates of Plastic Loadings in Water Bodies across North Carolina	• Establishes linkages between the presence of macroplastics and levels of microplastics • Creates a sampling protocol for plastics • Protects rivers feeding into estuaries from plastic pollution	Dr. Barbara Doll at North Carolina University bdoll@ncsu.edu Waterkeepers Carolina - Several Participating Waterkeeper Organizations in North Carolina Heather@soundrivers.org

The first global analysis of all the plastics in existence was conducted to assess production and consumption levels. The researchers found that 8.3 billion metric tons have been produced with 6.3 billion tons consisting of plastic waste and only 9% of the waste being recycled (Parker, 2018). The United States shares the same value of 9% for the amount of plastic recycled each year. The study estimated that 8 million metric tons of plastic are produced each year (Parker, 2018). They also discovered that plastic packaging makes up greater than 40% of non-fiber plastics, meaning it is the greatest contributor to non-fiber plastic pollution (Parker, 2018).

In the state, the North Carolina Coastal Federation with experts from other nonprofit organizations including Coastal Carolina Riverwatch, universities including Duke University, and local government agencies completed an assessment of plastic pollution in order to provide information that will be utilized in future policy development. They sourced their data from the Ocean Conservancy's International Coastal Cleanup data and the Marine

Debris Tracker App. They found that consumer plastics are the greatest source of debris in the state (Hallas, et al., 2018). Additionally, fishing gear, abandoned vessels, and infrastructure remains broken by storms were identified in the state's coastal waters, further damaging habitat and fish populations.

According to the National Oceanic and Atmospheric Administration (NOAA), marine debris is considered to be any "persistent manufactured or processed solid material discarded, disposed of, or abandoned in the marine and coastal environment" (National Oceanic and Atmospheric Marine Debris Program, 2014). Researchers have identified the main contributors to marine debris as retailers, the agricultural sector, shellfish mariculture, fisheries industry, commercial transporters, recreational boaters, coastal municipalities, tourists, and emergency rescue operations (Newman, et al., 2015).

Research has also been conducted to assist in understanding the impacts of plastic ingestion on marine life. The North Carolina Marine Mammal Stranding Network (NCMMSN) and the North Carolina Sea Turtle Stranding Network conduct necropsies which assist in determining if plastic ingestion was the cause of death for the individual and create a database of every studied stranded marine organism (Marine Mammal Stranding Network of the North Carolina Central Coast, n.d.). The Duke University Marine Laboratory in Beaufort, North Carolina researches the effects of plastic ingestion on marine life as well. Additionally, studies assess the amount of plastic ingested by specific fish species, and they have found resin pellets in 33-63% of individuals sampled (Miranda, Carvalho-Souza, 2016).

The Nicholas Institute for Environmental Policy Solutions at Duke University has developed a Plastic Pollution Working Group in order to promote collaboration among students and faculty. They aim to share their research with the goal of identifying solutions to the issues presented by plastic pollution. The interdisciplinary group includes professionals in engineering, chemistry, policy, corporate strategy and entrepreneurship, environmental toxicology, marine conservation, and emerging technologies and bioinformatics. Researchers from Duke University found that sea anemones tend to consume available

polyethylene due to the “tastiness” of additives found in plastics. After feeding the anemones pellets of polyethylene, they found that the concentration of most elements were similar to the control group, but the lead concentrations were significantly greater for the experimental group (Diana, 2020).

Microplastics' ability to carry microorganisms and contaminants when ingested has been named the Trojan Horse effect. One group of scientists at Duke University studied if the effect would impact the toxicity of nanoplastics and evaluated whether it had an effect on the biodistribution of the contaminants (Trevisan, et al., 2020). Finally, they investigated whether the effect influenced the mitochondrial toxicity of nanoplastics.They dosed zebrafish embryos with nanoplastics and found they did cause changes in embryonic and larval development. However, they did find nanoplastic particles have varying negative effects on mitochondrial energy metabolism. This study found that early development zebrafish experienced high percentages of pericardial edemas (98%) and curved tails (34%).

There are two main concerns with microplastic pollution: their physical and chemical impacts on organisms. One study completed by the Water Research Institute in Italy published significant findings relative to the chemical effects of plastic pollution on aquatic life. Microplastics obtain toxic chemicals by absorbing them from the environment or containing additives like monomers or oligomers from manufacturing (Campanale, et al,. 2020). The additives are used to increase the plastic products’ resistance to temperature, mold, bacteria, fire, and electricity (Campanale, et al., 2020).

Many of these toxic chemicals such as BPA, phthalates, and brominated flame retardants are classified as endocrine disruptors. These chemicals impact the development of the endocrine system and the functioning of organs that are responsive to hormonal signals (Campanale, et al., 2020). They can be linked to hormonal cancers, reproductive problems, metabolic disorders, asthma, and impaired neurological development.

Additionally, heavy metals including antimony oxide, aluminum oxide, and zinc borate are used in polymer products such as flame retardants, fillers, and stabilizers (Campanale, et al., 2020). Zinc, lead, chromium, and cadmium are utilized as colorants. The EPA has identified some of these heavy metals as "known" or "probable" human carcinogens. High levels of heavy metals can cause cellular and tissue damage, mimic estrogen activation, and breast cancer (Campanale, et al., 2020). With plastics acting as vectors for the heavy metals and entering bodies of water at a rapid rate, aquatic organisms are exposed to these harmful substances. One study published in Environmental Health Perspectives placed broken up pieces of plastic products in saltwater or alcohol and found that over 70% of the products released chemicals similar to estrogen (Hamilton, 2011). Scientists have found links to certain plastic chemicals such as BPA to cancer, diabetes, heart disease, and other illnesses.

Not only does plastic pollution poison and trap marine life, researchers have found that plastic causes increased water temperatures. The accumulation of material on the surface develops an insulation layer that can create an unsuitable environment for wildlife (Rosane, 2021). Researchers from the University of Tasmania's Institute for Marine and Antarctic Studies (IMAS) studied two remote islands' beaches, Henderson Island and the Cocos Islands. They discovered a large quantity of debris on the islands and determined that the plastic elevated daily maximum temperatures by 2.45 degrees Celsius and decreased daily minimum temperatures by 1.5 degrees Celsius (Rosane, 2021). Ectotherms such as crab and sea turtles are especially vulnerable to the fluctuations in water temperatures because they rely on external temperatures to regulate their body temperature (Rosane, 2021). Plastic is often mistaken for shells by hermit crabs causing deaths by the hundred and even thousands on the two islands.

One specific study completed with larval and juvenile Black Sea Bass discovered that there was trophic transfer from the microzooplankton exposed to microplastics when they were consumed by the Black Sea Bass. The scientists found that the immune response of the fish decreased with an increased concentration of microplastics in the organisms (Steinbarger,

et al., 2021). The larval fish did not prefer the non-exposed microzooplankton over the microzooplankton containing microplastics (B. Monteleone, personal communication, July 27, 2021).

Similarly, some of the same researchers in the Black Sea Bass study found that trophic transfer of microplastics can be documented in larval inland silversides who eat microzooplankton. They noted significantly lower weight values of larvae exposed to microplastics in comparison to the unexposed organisms after 16 days (Athey, et al., 2020). Also, they found individuals were more susceptible to predation when exposed to DDT, a contaminant associated with microplastics, because the chemical affects locomotion and predator escape response (Athey, et al., 2020).

Finally, researchers at North Carolina State University, including Dr. Barbara Doll, are generating estimates of loadings of macroplastics and microplastics coming from rivers and entering sounds. They are looking for linkages between trash and the amount of microplastics found at a given site. The most common items contributing to microplastic pollution in the Neuse River Basin are styrofoam, plastic bottles, plastic bags, plastic films (polystyrene) (B. Doll, personal communication, July 9, 2021).

Recommended Future Actions:

Type of Research	Water Quality Impacts
Green Chemistry Research	• Protects aquatic ecosystem from harmful effects of toxins found in plastics • Reduces plastic pollution
Studies Focused on the Interactions of Molecules in the Environment and the Physiological Effects on Fish	• Defines the implications of chemicals on wildlife, fish, and flora • Assists in creating regulations and criteria levels for chemicals • Protects aquatic populations from toxins and plastics

Developing Technologies to Identify Plastics in Aquatic Organisms	• Increases our understanding of how prevalent plastics are inside aquatic organisms • Improves technologies and necropsie techniques to identify causes of death in organisms due to plastics, therefore preventing other deaths
Research Focused on Identifying Endocrine-Disrupting Chemicals	• Develops a greater scientific understanding of chemicals interactions with fisheries • Assists in identifying specific chemicals that are endocrine-disrupting in order to create regulations

Overall, plastics research, particularly its effects on the environment, is fairly new and limited. Dedicating more time and resources to green chemistry research could assist in the development of alternatives to plastic products. It is essential to study the lifecycle of new biodegradable polymers and their impacts on marine organisms (Gallo, et al., 2018). Evaluating the chemical makeup of products before they are widely produced will prevent the over-production of toxic materials that tend to end up in landfills and the environment.

Also, scientists have begun to study the interactions of molecules found in plastics with the environment, but there is still a significant lack in understanding of the exact extent of molecules leaching into water. In the future, discovering the quantity of molecules entering aquatic ecosystems when plastics pollute the environment will assist in developing regulations and criteria for chemical levels. Specific elements such as mercury and silicone have been investigated, but broadening the research will greatly contribute to plastics research.

Research published in the journal, Environmental Sciences Europe found an association between the exposure of microplastics to negative effects on marine populations (Gallo, et al., 2018). Specifically, they discovered micro- and nano-plastics decreases zooplankton species' ability to survive and increases their mortality rate (Gallo, et al., 2018). Also, crustaceans had decreased survival and fecundity when exposed to plastics. Overall, the Joint Research Centre of the EC, found that plastic ingestion negatively affects reproductive capacity and survival of marine life from lower trophic levels (Gallo, et al., 2018).

However, the authors of this research acknowledge a definite knowledge gap in our understanding of the extent of the effects chemicals have on marine species as a result of plastic ingestion. This study is one of a few that evaluates the impacts of toxins from plastics on marine life, and there is a need to further investigate the chemical implications of plastic pollution. Additionally, the physiological effects of microplastics on fish and marine life are not well understood and require increased laboratory studies (Baechler, et al., 2019).

Though Duke has begun research on the effects of plastic ingestion on marine life through necropsies, it is difficult to identify microplastic pieces inside the animal or fish. Moving forward, developing and improving the technologies to locate microplastics inside of organisms will greatly assist in improving our understanding of their prevalence in the marine environment and contributions to deaths.

There are relevant studies that identify endocrine-disrupting chemicals (EDCs) in fish and other marine life. However, we still do not know what proportion of chemicals act as EDCs. Also, there is a need for more research regarding the interactions these chemicals have with the environment, specifically their impacts on fisheries.

Advocacy, Outreach, and Education Assessment

Current Actions:

Type of Advocacy, Education	Water Quality Impacts	Lead Organization
Public Educational Material Developed by Environmental NGOs	• Decreases plastic consumption and pollution • Teaches proper plastic disposal techniques	North Carolina Marine Debris Symposium www.ncmarinedebrissymposium.com / Coastal Carolina Riverwatch www.coastalcarolinariverwatch.org NC Division of Environmental Assistance and Customer Service NCDEACS https://deq.nc.gov/about/divisions/environmental-assistance-customer-service Carolina Recycling Association http://www.cra-recycle.org North Carolina Solid Waste Association of North America NCSWANA https://ncswana.org Plastic Ocean Project https://www.plasticoceanproject.org Wrap Recycling Action Program https://www.plasticfilmrecycling.org/about/

		North Carolina Stream Watch: NCDEQ 919.707.9009 North Carolina Aquariums' Initiative: In Our Hands 1-800.406.FISH (3474) NC Marine Debris Action Plan https://www.nccoast.org/wp-content/uploads/2020/01/N.C.-Marine-Debris-Action-Plan.pdf
Advocating for Plastic Regulations	• Eliminates use of styrofoam and other products that break down easily and pollute aquatic ecosystems • Encourages plastic reduction efforts	Environment America https://environmentamerica.org/feature/ame/wildlife-over-waste
Companies Publicizing Plastic Reduction Efforts	• Reduces plastic consumption, waste, and pollution • Addresses social, environmental, and economic impacts of plastic production and pollution • Encourages other companies to	Ocean Friendly Establishments https://www.oceanfriendlyest.com NC Green Travel https://deq.nc.gov/about/divisions/environmental-assistance-customer-service/nc-green-travel-program

	participate in plastic reduction initiatives	
Ocean Friendly Establishments Certification	• Decreases plastic consumption and waste in local communities • Advocates for alternatives to plastics, therefore reducing pollution	Ocean Friendly Establishments https://www.oceanfriendlyest.com Oceanfriendlyestablishments@gmail.com
Plastics Policy Inventory	• Identifies policy gaps in plastic regulatory actions • Promotes sustainable policy development and aquatic ecosystem protection	Duke University (Plastic Pollution Working Group) plastics@duke.edu
National Caucus of Environmental Legislators' Initiatives	• Provides the public with information and data related to plastic pollution and its effects on health • Provides educational information about current policy initiatives	National Caucus of Environmental Legislators' Initiatives (202) 744-1006

Beach and River Clean-ups	• Creates concern for local recreational and fishing sites and their protection • Reduces amount of plastic currently in bodies of water • Encourages decreased consumption of plastics	NC Marine Debris Symposium www.ncmarinedebrissymposium.com Check out local environmental organizations!

Environmental groups have championed the cause of plastic consumption and production reduction fervently. Some programs developed to assist in providing educational material in regard to appropriate plastic disposal and strategies to reduce our individual consumption patterns include the Wrap Recycling Action Program; the North Carolina Stream Watch; the Adopt a Beach program, and the North Carolina Aquariums' initiative, In Our Hands (Hallas, et al., 2018).

Environment America is advocating for a ban of Styrofoam (polystyrene foam) take-out cups and containers. Polystyrene is particularly dangerous because it breaks apart easily, and it exists in the environment as extremely small particles for hundreds of years. Environment America has had success in advocating for plastic reduction efforts through the passing of statewide laws encouraging recycling and a plastic bag ban in the whole state of California (Environment America, 2019).

Some companies are resisting the transition from plastics, but others are contributing to the initiative. For example, McDonald's has committed to phasing out foam cups and containers across the globe and replacing them with 100% recycled products (Environment America, 2019). Locally, retailers who decide to use alternatives to single-use plastics may receive the Ocean Friendly Establishments certification. This program was developed by

two non-profit organizations located in WIlmington, Plastic Ocean Project and the Cape Fear Surfrider Foundation Chapter (Hallas, et al., 2018).

Duke University Marine Laboratory is at the forefront of outreach regarding this issue with the development of their community science program. Fourth grade classes in Carteret County participate in beach cleanups and learn about using marine debris in art, the recycling process, and scientific data collection. Also, the Nicholas Institute for Environmental Policy Solutions at Duke created a database of public policies that regulate plastic pollution around the world since 2000 called the Plastics Policy Inventory. The inventory includes over 310 policies that anyone can download to learn more information about the legislation. The goal of the database is to identify where there are policy gaps, analyze the policies' effectiveness, and determine ways current legislation can be improved or new legislation can be developed (Plastics Policy Inventory, 2020).

At the federal level, the National Caucus of Environmental Legislators (NCEL) provides substantial information regarding the environmental and public health implications of plastics to the public (National Caucus of Environmental Legislators, 2021). Also, they describe policy options for managing plastic waste and details regarding current bills and enacted legislation.

Finally, involving community members in ocean and river cleanups assists with raising awareness of the issue. The public visualizes the extent of plastic contamination in their community when participating in trash cleanup activities. Creating the connection between their favorite fishing or recreational sites and the quantity of plastic entering the system. Therefore, participants are developing a concern and encouraging involvement in plastic reduction initiatives.

Recommended Future Actions:

Type of Advocacy, Education	Water Quality Impacts

Educational Material Regarding Alternatives to Plastics	• Decreases plastic consumption and a market for those products • Reduces amount of plastics entering aquatic ecosystems
Writing, Calling, and Lobbying Legislators	• Increases protection of water quality and aquatic habitats • Informs politicians on local environmental issues
Public Outreach regarding Human Contribution to Aquatic Plastic Pollution from Land Sources	• Educates public on strategies to reduce littering and improper plastic disposal • Reduces quantity of plastics entering streams and estuaries
Increasing Corporate Transparency	• Reduces consumption of harmful plastic products • Decreases plastic pollution and protects the aquatic environment from toxins and entanglement

Working with producers and providing educational material regarding the use of plastic packaging in their production processes could assist in encouraging alternatives to plastics. Another method to assist in reducing marine litter would be to provide technical assistance and waste management techniques to stakeholders and provide methods to reduce our individual plastic consumption (Gallo, et al., 2018).

The translation from the science of chemistry to policy development is complex because a small amount of actual research or data is used by politicians. Making chemistry more approachable and educating political leaders and the public on the chemical makeup of our products and their implications on the environment and public health may encourage regulatory action.

Additionally, NGOs, environmental groups, and stakeholders can express concerns to our legislators in order to inform leaders about current, local water quality issues. Lobbying,

writing, and calling representatives and discussing fishermen's worries related to the implications of increased plastic pollution could influence policy-makers. The fishing industry, tourism, and aquaculture are economically significant to North Carolina, but they are vulnerable to the effects of plastic contamination on the fish and shellfish populations. Therefore, the public can push for initiatives such as plastic bag bans or a plastic bottle bill to decrease the production and consumption of plastic in the state, and protect the economic and ecological integrity of the fisheries.

Also, providing educational material about the sources of plastic pollution in marine and freshwater ecosystems will help to decrease littering. 90% of plastic debris comes from terrestrial sources such as littering when plastics are thrown on the ground and then washed through storm drains to local waters. Making the connection between our actions on land and their effects on aquatic environments will persuade the general public to participate in proper plastic disposal practices.

The public is not completely aware of the prevalence of plastics containing dangerous toxins in our products. For example, the rain that falls on a plastic fence or garbage can every week in the spring eventually breaks down the plastics and carries dangerous chemicals with it to local streams and rivers. Informing the public on sources of plastic pollution on their own property as well as the public health risks associated with exposure to these products. Also, increasing corporate transparency will allow the public to understand what kind of dangerous additives are used in plastics. Then, they can make a decision about what type of products they want to buy and keep in their households.

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