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Wicked Ideas for Wicked Problems: Marine Debris and the Complexity of Governance

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WICKED IDEAS FOR WICKED PROBLEMS:

MARINE DEBRIS AND THE COMPLEXITY OF GOVERNANCE

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ABSTRACT

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Myriad challenges regarding earth's common spaces, those unregulated by sovereign state authorities, mount and intensify as resources diminish and competition for commercial, scientific and security advantages increases; the pollution and degradation of those spaces simultaneously expands. Threats to the global commons complicate efforts to achieve international consensus which impedes attempts to develop effective governance. As an example, marine debris is a growing problem and is an existential threat to the global commons.

This dissertation aims to characterize marine debris as a wicked problem and explores the complexity of governance in the global ocean commons by answering two fundamental questions. Under what condition(s) does regulating debris in the marine commons pose unique governance challenges? Is the wicked problem of marine debris unsolvable?

An interdisciplinary, mixed methodology approach is used, to include the development of a novel System Dynamics model, to explore the reinforcing cycles of exponential growth of marine debris. The design and analysis demonstrate multiple variables as components of a larger system and explore their dynamic interaction.

This study finds that marine debris is indeed a wicked problem. Wicked problems are inherently unique and because of their nature, extant models of governance fall short in tackling them. By modifying existing norms, governance can be adapted to confront marine debris with meaningful results and, by extension, other wicked problems, through collaboration at all levels and by adopting a progress-centered versus solution-oriented approach. Intractable problems are intrinsically difficult to address and requisite governance actions need to be as multi-faceted and dynamic as the problems themselves.

This dissertation is dedicated to my Mother and Daddy:

For my mother who believed I could achieve anything I put my mind to and who has always been my biggest cheerleader.

For my daddy who supported every undertaking I chose to pursue and who instilled in me a fighting spirit guided by integrity. “Fight Fair” - Daddy

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NOMENCLATURE

CCS	Carbon Capture and Storage
CFC	Chlorofluorocarbon
CLD	Causal Loop Diagram
COP	Conference of the Parties
CO^2	Carbon Dioxide
DDT	Dichlorodiphenyltrichloroethane
DV	Dependent Variable
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GMP	Gross Marine Product
GPP	Global Plastic Production
IGO	Intergovernmental Organization
II	International Institution
IMO	International Maritime Organization
IO	International Organization
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
IR	International Relations
Km	Kilometer
MARPOL	International Convention for the Prevention of Pollution from Ships – shortened to Maritime Pollution
MNC	Multinational Corporation
MPRSA	1972 Marine Protection, Research and Sanctuaries Act
MPW	Mismanaged Plastic Waste
MT/Mt	Million Metric Tons
NGO	Non-Governmental Organization
NM	Nautical Mile
NOAA	National Oceanic and Atmospheric Administration
ODS	Ozone Depleting Substance
OECD	Organization for Economic Co-operation and Development
O^2	Oxygen
PCB	Polychlorinated Biphenyls
Pergub	Gubernatorial Regulation - Bali
PEW	PEW Charitable Trust
pH	Power of Hydrogen
SDG	Sustainable Development Goals
SES	Social-Ecological System
UK	United Kingdom

UN	United Nations
UNCLOS/LOSC	United Nations Convention on the Law of the Sea/Law of the Sea Convention
UNEP	United Nations Environment Programme
UNESCO	United Nations Education, Science and Cultural Organization
US	United States
USD	United States Dollars
WMO	World Meteorological Organization
WTO	World Trade Organization

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CHAPTER I

INTRODUCTION

"For that which is common to the greatest number has the least care bestowed upon it. Everyone thinks chiefly of his own, hardly at all of the common interest; and only when he is himself concerned as an individual. For besides other considerations, everybody is more inclined to neglect the duty which he expects another to fulfill..."[1]

- Aristotle

The myriad challenges facing earth's common spaces, those unregulated by sovereign state authorities, multiply and intensify as resources diminish and competition for commercial, scientific and security advantages increases; the pollution and subsequent degradation of those spaces simultaneously grows as well. State security, and threats to that security, is often the impetus for action to develop governance measures within traditional sovereign boundaries. Expanding to the global commons, however, complicates efforts to achieve international consensus on the threats, which impedes efforts to develop governance measures. As an example, marine debris is a growing problem in and an existential threat to the global commons.

This dissertation explores marine debris as a wicked problem and the complexity of governance in the global commons by answering two fundamental questions: 1) Under what condition(s) does regulating debris in the marine commons pose unique governance challenges? and 2) Is the wicked problem of marine debris unsolvable? To address these

[1] Aristotle, *Politics*, trans. Benjamin Jowett (Los Angeles: Indo-European Publishing, 2009), 21. This quote is located in Part III of Book II.

questions, a mixed-method approach is used with a qualitative review and discussion of theory and governance, and a quantitative assessment of marine debris through the utilization of an original model. The primary hypothesis argues that wicked problems such as marine debris are inherently unique and because of their nature, extant models of governance fall short in tackling them.

The use of a common space for individual, corporate or state purposes without due consideration of long-term detrimental effects on the space is a critical challenge facing the international community. Following publication of Garrett Hardin's seminal article in 1968 "The Tragedy of the Commons" which addressed the long-term deterioration costs of individual interests and the utilization of the commons without consideration of the compounding effects, there has been a growing awareness of the degradation of common areas.[2] While principally focused on the exploitation of resources in the global commons and the societal tendency to prioritize personal gain above that of the public good, he also addressed the tragedy of the commons in terms of pollution and degradation, lamenting, "it is not a question of taking something out of the commons, but of putting something in."[3]

Hardin's use of the rational person theory elucidates the lack of successful self-regulation at all levels (individual, corporate, government). He asserts that a "rational man finds that his share of the cost of the wastes he discharges into the commons is less than the cost of purifying his waste before releasing them."[4] It is not only the current high cost of

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[2] Elinor Ostrom, *Governing the Commons : The Evolution of Institutions for Collective Action* (Cambridge: Cambridge University Press, 1990), 2.

[3] Garrett Hardin, "The Tragedy of the Commons," *Science* 162, no. 3859 (1968): 1245.

[4] Ibid.

collection and purification that allows this pervasive release, but also a lack of connectivity to the problem because it resides in the commons which renders it distant and therefore, intangible to many. This lends to his claim that we become "locked into a system of 'fouling our own nest,'"[5] without incentive to sufficiently regulate our behavior due to a misguided focus on a near-term cost analysis. This myopic perspective falsely leads to the conclusion that if the immediate costs of pollution and degradation to the marine environment do not outweigh the costs of changing behavior, then it is "something others can deal with" because it is not a priority to the evaluator. In contrast, long-term analysis that reveals the damaging effects highlights this costly and flawed approach. Sadly, this faulty thinking has sanctioned the decades of uncontrolled flow of millions of tons of debris into the marine environment, resulting in an existential threat that is only recently gaining more wide-spread recognition.

Scholarly writing on marine debris is relatively new in the International Relations literature, with most topic-related work written for the physical science fields. Yet with increasing awareness of the problem, there is a nascent body of scholarly work taking shape in the International Relations field. This project intends to contribute to scholarly literature in several ways: it asserts the amount of debris both entering and leaving the ocean is dependent almost entirely on governance, so imagining new, less-bounded conceptions of governing complex problems of the global commons is imperative; it argues that the most appropriate theoretical application for marine debris is as a wicked problem; and through the design of a System Dynamics model, constructs a useful tool to provide an unconventional yet functional,

[5] Ibid.

and thus valuable, means through which to understand this problem, precisely because traditional methods are proving less than adequate.

To develop a deeper understanding of the marine debris problem, Chapter 2 will canvas the relevant literature to review the geographical context of the ocean, including discussion on the role of rivers, and describe its intractable human interdependence on the resource. This will frame the marine environment through functions and activities that contribute to the health and/or degradation of the marine ecosystem.

To further elaborate on the human link with the ocean, five critical functions will be introduced to demonstrate this symbiotic relationship which constitutes a major source of the global ecological balance. Oxygen and carbon dioxide regulation, climate regulation, food source, transportation, and wealth production will each be examined and evaluated to provide perspective of their respective additional stressors that, exacerbated by marine debris, further heighten the assault on the marine environment.

A review of the history and process of ocean contamination and degradation follows and includes an assessment of four key areas. The first is an appraisal of Post-Industrial Revolution growth and its adverse outcomes while the second provides an overview and brief examples of the phenomenon of ocean warming. A brief explanation of ocean acidification and its impacts follows with the examination of the category of pollution in which marine debris is included. The critical contribution that coastal waters and rivers make to the larger debris problem comprises the final section. Several components of marine debris are explored, but it is plastics, microplastics and toxins that are the central focus of this work given their harmful and pervasive nature. The complexity and rapidly compounding pressure that marine debris exerts on an already stressed and critical ecosystem elevates its characterization to an existential threat.

When faced with an existential threat, it is essential to take actions to mitigate the threat in order to preserve the element at risk. Chapter 3 assesses governance as the means by which to address these threats and also considers intrinsic challenges that often hinder governance's ability to curtail and/or reverse threats. The problem of plastic marine debris is exacerbated by virtue of its location in one of the global commons, an area traditionally considered an ungoverned space. To better conceptualize and appreciate this task, governance will be defined and its applicability to the marine commons explored.

Chapter 3 begins by reviewing the historical underpinnings and relevant literature of governance, and then discusses the misconception that government and governance are one in the same. A practical definition of governance is offered for use throughout this project. A review of the multi-level applicability of governance at the sub-national, national and supra-national level as well as a brief look at participatory governance with pertinent examples will follow. A detailed look at the supra-national level reveals several key International Organizations and International Institutions that play a significant role in ocean governance. At the same time, these international entities are further compared and contrasted to explore the division of various international actors.

Next, governance in the global commons is examined utilizing the London Convention and London Protocol, the United Nations Convention on the Law of the Sea and the Montreal Protocol as examples of global efforts to govern areas specific to the marine commons and its unique challenges. Finally, an analysis of measures of governance effectiveness will be presented in order to ground the assessments through the remainder of this project, specifically asserting that effective measures of governance are characterized by changes in behavior that produce a desired outcome.

Theoretical underpinnings and methodology are combined in Chapter 4. This project employs a mixed methodology that predominantly uses a qualitative approach. It proposes a novel System Dynamics model to further the case for theoretically conceptualizing marine debris as a wicked problem, and proposes a second hypothesis that marine debris is, in fact, a wicked problem.

To add context, a review of the relatively new theory of Wicked Problems and its literature will be presented, and the ten characteristics outlined by Horst W. J. Rittel and Melvin M. Webber will be discussed. Similarly, this chapter includes an overview of system dynamics and its functions and applications.

The model suggests a phased development of a causal loop diagram of the plastic marine debris system and is designed with 14 variables. While there are valid arguments for the selection of numerous others, these particular variables were chosen to present a meaningful tool that more accurately conceptualizes the relationships within the system and further facilitates understanding of the implications of the system's behavior.

This unique heuristic expands its explanatory potential in Chapter 5 with the presentation of stock and flow simulations. The model is calibrated by utilizing real-world data where available and by substituting representative notional values in the remaining areas. A delay function reflects real-world evolution since the variable effects and their associated changes do not occur immediately. The simulations demonstrate the potential of such an approach for guiding the development, implementation and enforcement of useful governance.

Chapter 6 reviews the implications of the model and their applications are discussed while a third hypothesis is suggested: Contrary to existing norms, governance can be adapted to confront marine debris with meaningful results and, by extension, other wicked problems, through a reframed progress-centered versus solution-oriented approach. Remedy of an isolated problem is replaced by modifications to a complex and dynamic system with participation required at all levels of governance. Further discussion showcases how the model can aid in expanding governance effectiveness by reconceptualizing wicked problems. Importantly, the discussion highlights that, while the totality of marine debris is a wicked problem, it is not deemed inaccessible. The chapter closes by including limitations of the study and recommendations and thoughts on future work.

CHAPTER II

THE WORLD'S OCEAN

"Even if you never have the chance to see or touch the ocean, the ocean touches you with every breath you take, every drop of water you drink, every bite you consume. Everyone, everywhere is inextricably connected to and utterly dependent upon the existence of the sea."[6]

-Dr. Sylvia Earle, Former National Oceanographic and Atmospheric Administration Chief Scientist and National Geographic Explorer-in-Residence

Introduction

The relationship between the world's ocean and its stakeholders is complex and is characterized by an inseparable bond that exists between humans and our global marine environment. According to the United Nations Education, Science and Cultural Organization (UNESCO), the ocean is responsible for making "the earth habitable for people, by providing and regulating the climate, weather, oxygen, food, jobs and many ecosystem services."[7] Yet, it has long been acknowledged that the ocean is not only being depleted of its resources, but faces numerous challenges from acidification to rising temperatures to becoming an ever-increasing repository of marine debris. This complex interaction, placed under great stress during the more recent portion of the Anthropocene era, presents a global problem, one that is

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[6] Sylvia A. Earle, *The World Is Blue: How Our Fate and the Ocean's Are One* (Washington, D.C.: National Geographic, 2009), 17.

[7] Scientific and Cultural Organization United Nations Educational, "UNESCO: Building Equitable, Inclusive, Green Societies," http://www.unesco.org/new/en/natural-sciences/ioc-oceans/focus-areas/rio-20-ocean/blueprint-for-the-future-we-want/marine-pollution/facts-and-figures-on-marine-pollution/.

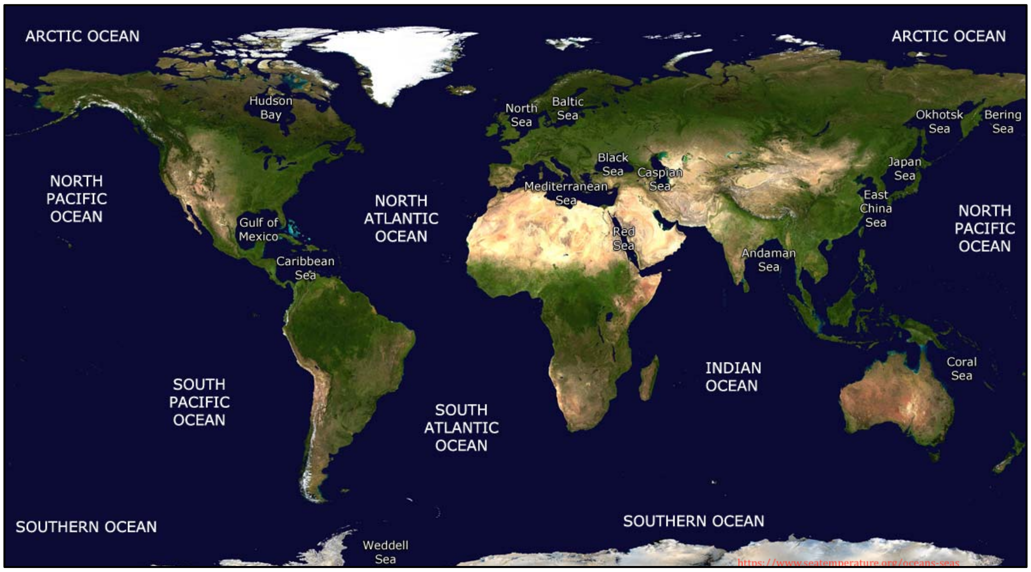
manifesting into an existential threat. To better understand this dynamic, this chapter will provide an overview of the earth's ocean's functions, highlight significant stressors that are compounded by marine debris, provide a brief historical perspective of ocean contamination and then explore the nature and impact of the existential threat that is marine debris, with an emphasis on plastics.

The Complexity and Importance of the Ocean

The ocean is the largest geographical component on earth covering more than 70 percent of the planet. It is technically connected as one continuous body of water but is divided, for human organizational convenience, into five oceans. Those five oceans are, in descending order by size, the Pacific, Atlantic, Indian, Southern and Arctic but, unless specifically addressed as one of these five oceans, further references will defer to the concept of one continuous ocean. Additionally, there are more than a dozen major seas, smaller saline bodies of water usually adjoined to the ocean, with a noted exception - the Caspian Sea – which borders no sea or ocean. A representation of the five oceans and several of the major seas is provided in Figure 2.1.

Figure 2.1

The World's Five Oceans and Several Major Seas



Source: Cleaner Oceans Foundation Ltd. [8]

In order to further understand the vastness of the ocean, one might consider that the smallest of the five oceans, the Arctic, covering roughly 5.5 million square miles, is more than 30 percent larger than the landmass of China, the planet's fourth largest country by landmass and most populated.

To further understand human interdependence with the ocean, consider that 192 countries have ocean coastline and "nearly 2.4 billion people (about 40 per cent of the world's

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[8] Blue Growth, "Oceans & Seas of the World," Cleaner Oceans Foundation, Ltd., https://www.blue-growth.org/Oceans_Rivers_Seas/Index_Oceans_Seas_Bays_Gulfs_Of_The_World_%20A_To_Z_Lists.htm.

population) live within 100 km (60 miles) of the coast."[9] These littoral states have a symbiotic relationship with the ocean where the population depends on the ocean in numerous ways such as for commercial fishing, tourism and recreation, shipping and transportation, ports and harbors, and ship and boat building. Consequently, these states simultaneously care for the health of the ocean upon which their livelihood depends but also contribute to its degradation.

Numerous rivers that originate on land and flow into the ocean not only augment the natural circulation of the ocean but also act as a conveyor belt for fresh water, silt, pollutants and debris that originate within the global landmass. While numbers and definitions vary, there are approximately 150 major rivers - those which have great length, volume, velocity and/or width - that contribute significant commercial, economic, health and environmental functions across the planet; generally, all flow to the ocean. Meanwhile, thousands of smaller rivers canvass the earth, most of which also flow into the ocean.

These environments – oceans, seas, and rivers - contribute to the health and/or degradation of the marine ecosystem which is a complex interaction of living organisms with non-living elements in the marine environment. The ocean is composed of smaller ecosystems, each contributing to the broader marine ecosystem that provides nutrients, oxygen, climate regulation and numerous other essential aspects of life on earth.

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[9] United Nations, "The Ocean Conference Factsheet: People and Oceans," ed. United Nations (New York: United Nations, 2017).

Five critical functions of this symbiotic relationship between humans and the ocean constitute a major source of the global ecological balance: oxygen (O^2) and carbon dioxide (CO^2) regulation, climate regulation, food source, transportation, and wealth production.

Oxygen and Carbon Dioxide Regulation

One of the most critical functions performed by the ocean is providing approximately 50 percent of the oxygen produced globally.[10] This can be contextualized as roughly every other breath a human takes. This function is performed through the process of photosynthesis in which small plant-like organisms, known as phytoplankton, utilize sunlight to convert carbon and water into oxygen and glucose. Oxygen is essentially a byproduct and glucose is the manufactured element phytoplankton seek as their food source. While land-based plants are often larger in size and perform a similar function, by virtue of the ocean's vastness and thus the much larger ratio of phytoplankton to land-based plants, the ocean naturally has a large capacity to produce oxygen.

As a result of the ocean covering almost two-thirds of the planet's surface and through the process of photosynthesis, the ocean also becomes the largest carbon sink, a natural environment that absorbs CO^2 from the atmosphere - currently estimated to be 30 percent of the anthropogenic emissions of CO^2.[11]

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[10] National Research Council, "From Monsoons to Microbes / Understanding the Ocean's Role in Human Health," (Washington, D.C: National Academy Press, 1999), 18.

[11] "IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change," ed. T.F. Stocker, et al. (Cambridge, 2013), 11.

In conjunction with a higher volume of CO^2 stored in the ocean, the unhealthy biproduct of ocean acidification also increases owing to a series of chemical reactions that occur when CO^2 is absorbed by seawater. Ocean acidification is defined as the increasing level of acid volume in the ocean resulting from rising CO^2 in the earth's atmosphere mixing with water to create carbonic acid, or is the reduction of seawater pH levels. According to the National Oceanic and Atmospheric Administration (NOAA), ocean acidification has increased 30 percent since the beginning of the Industrial Revolution.[12] To counter the compounded effects of both naturally-occurring and human-generated CO^2, there must be increased efforts to maintain the balance between photosynthesis and carbon sequestration in order to sustain life on earth. Unfortunately, it appears few sufficient measures have been taken to fight the rapidly increasing carbon load that will eventually tip the balance.

Climate Regulation

In addition to its ability to sequester carbon, the ocean plays a major role in climate regulation by both reflecting the sun's light and heat (known as *albedo)* and absorbing heat. While the ocean's albedo is rather low compared to the reflective properties of snow- and ice-covered regions of the globe, its capacity to absorb heat is remarkable. The Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report of 2013 noted that approximately "93% of the excess heat energy stored by the earth over the last 50 years is found in the

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[12] Pacific Marine Environmental Laboratory National Oceanic and Atmospheric Administration, "What Is Ocean Acidification?," https://www.pmel.noaa.gov/co2/story/What+is+Ocean+Acidification%3F.

ocean."[13] The challenge this presents is that the ocean is warming at a much greater rate than was previously estimated which is pushing the ocean's capacity to absorb heat to limits that will create irreversible damage to myriad ecosystems. As ecosystems are damaged, the very organisms that have enabled the ocean to absorb heat and CO^2 while producing oxygen are threatened which risks their elimination and thus compromises the ocean's ability to function as both an oxygen and CO^2 regulator as well as a temperature regulator. Additionally, wind and ocean current patterns that circulate warm and cool water are crucial to maintaining global biodiversity or particular habitats and ecosystems.

Food Source

The ocean is rich in natural resources and one of the most significant is the food it produces in the form of both plants and animals. Given a global population in excess of 7.5 billion people, the ocean provides almost 20 percent of the world's human consumption of animal protein which equates to approximately 150 million metric tons (Mt) each year. This not only includes fish, but also generally includes shellfish and crustaceans. While marine mammals, sea turtles and algae are often not included in these figures, they do account for a smaller portion of human nutrition which helps explain how the ocean is the primary source of animal protein "along with essential micronutrients and fatty acids for three billion people."[14] This is perhaps more noteworthy for those in the developing world where fish and other

[13] "IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change," 260.

[14] Food and Agriculture Organization of the United Nations, "Global Aquaculture Advancement Partnership (GAAP) Programme," (United Nations), 2.

aquatic species account for a significantly higher proportion of food than in the developed world.[15]

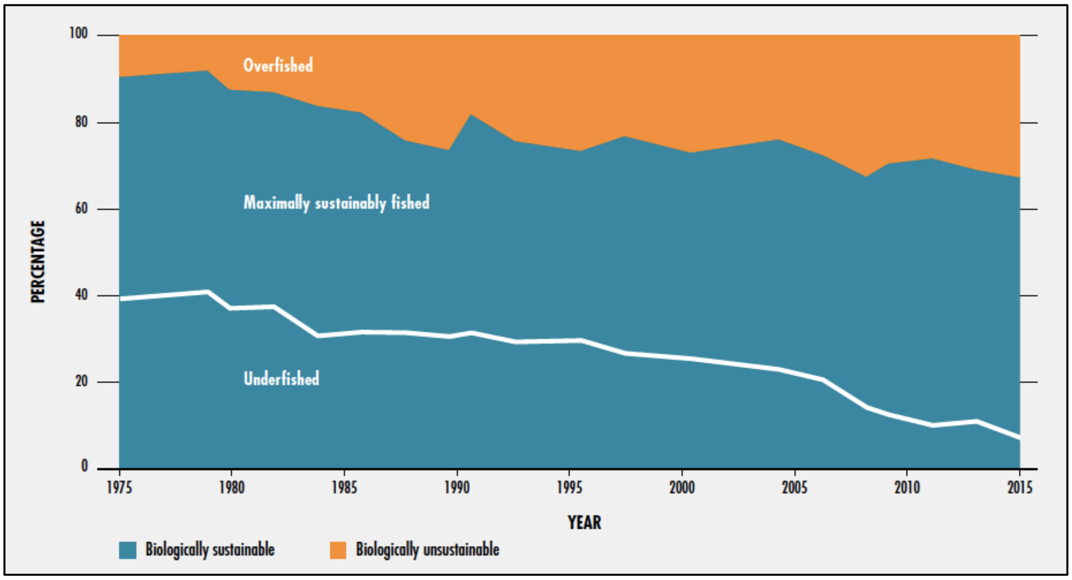
According to the United Nations's Food and Agriculture Organization (FAO) 2018 report on the *State of World Fisheries and Aquaculture*, since 1961 "the average annual increase in global food fish consumption … outpaced population growth … and exceeded that of meat from all terrestrial animals combined."[16] This raises increasing concern regarding sustainability of the ocean's food resources. With 33.1 percent of global fish stocks estimated to be overfished, (fished at biologically unsustainable levels), this category of fish stocks has seen a notable increase of 20.1 percent from 1974 when the biologically unsustainable levels of the global fish stocks were estimated to be only 10 percent (Figure 2.2).

[15] European Commission, "Food from the Oceans: How Can More Food and Biomass Be Obtained from the Oceans in a Way That Does Not Deprive Future Generations of Their Benefits?," (Brussels, 2017), 13.

[16] Food and Agriculture Organization of the United Nations, "The State of World Fisheries and Aquaculture (2018) - Meeting the Sustainable Development Goals," (Rome, 2018).

Figure 2.2

Global Trends in the State of the World's Marine Fish Stocks, 1974-2015



Source: Food and Agriculture Organization's "State of the World Oceans (2018) – Meeting the Sustainable Development Goals"[17]

Additionally, 59.9 percent of the global fish stocks were deemed fully fished in 2015, now termed as maximally sustainable fish stocks.[18] It has been determined that "Growth in the global supply of fish for human consumption has outpaced population growth in the past five decades, increasing at an average annual rate of 3.2 percent in the period 1961– 2013, double

[17] Ibid., 40.

[18] Ibid. No references are made to instances of illegal, unregulated and unreported catches; therefore, a reasonable assumption can be made that these figures are somewhat below actuals.

that of population growth."[19] If unchecked, this may lead to a rapid depletion of this critical resource. This highlights the critical importance of the ocean as a source of food, especially considering that estimates indicate a "global need for 70% more protein by 2050."[20]

Transportation

Another critical function performed by the ocean is transportation. Not only does the ocean function as a transport system for heat, moving it from the surface down through the water column while mixing with cold upwelling water to help regulate the global temperature, it also serves as a massive highway system for more than 200,000 known species that inhabit the aquatic environment. Many of these species migrate thousands of miles annually to rich hunting and feeding grounds or to climate appropriate breeding and birthing grounds.

Yet, perhaps the foremost point of states' interests regarding ocean transit is commercial transportation which influences the economic well-being of the state. According to the United Nations and its agency for maritime issues, the International Maritime Organization (IMO), approximately "80 percent of global trade by volume"[21] is conveyed by commercial shipping. Since the 1970s, seaborne trade has more than quadrupled in volume (Table 2.1).

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[19] Food and Agriculture Organization of the United Nations, "The State of World Fisheries and Aquaculture (2016) - Contributing to Food Security and Nutrition for All," (Rome, 2016), 6.

[20] European Commission, "Food from the Oceans: How Can More Food and Biomass Be Obtained from the Oceans in a Way That Does Not Deprive Future Generations of Their Benefits?," 13.

[21] United Nations Conference on Trade and Development (UNCTAD), "Review of Maritime Transport," (New York, 2018), 23.

This increased activity has the unfortunate side effect of also increasing global maritime pollution, as shipping is often seen to be a "major source of marine litter."[22]

Table 2.1

Seaborne Trade 1970 – 2017

(Millions of Tons Loaded)

Year	Crude oil, petroleum products and gas	Main bulks[a]	Other dry cargo[a]	Total (all cargoes)
1970	1 440	448	717	2 605
1980	1 871	608	1 225	3 704
1990	1 755	988	1 265	4 008
2000	2 163	1 295	2 526	5 984
2005	2 422	1 711	2 976	7 109
2006	2 698	1 713	3 289	7 701
2007	2 747	1 840	3 447	8 034
2008	2 742	1 946	3 541	8 229
2009	2 642	2 022	3 194	7 858
2010	2 772	2 259	3 378	8 409
2011	2 794	2 392	3 599	8 785
2012	2 841	2 594	3 762	9 197
2013	2 829	2 761	3 924	9 514
2014	2 825	2 988	4 030	9 843
2015	2 932	2 961	4 131	10 024
2016	3 055	3 041	4 193	10 289
2017	3 146	3 196	4 360	10 702

Source: United Nations Conference on Trade and Development (UNCTAD): Review of Maritime Transport 2018[23]

While efforts have been made to curtail ocean pollution, such as the 1973 International Convention for the Prevention of Pollution from Ships (commonly known as MARPOL, short for

[22] Michael Klages, Gutow Lars, and Bergmann Melanie, *Marine Anthropogenic Litter* (Springer, 2015).

[23] United Nations Conference on Trade and Development (UNCTAD), "Review of Maritime Transport," 5. (Refer to RMT 2018 for detailed explanation regarding superscript "a" annotation for Main bulks and Other dry cargo.)

Maritime Pollution) "compliance and enforcement remain significant problems."[24] When noting the dramatic increase in shipping tonnage from Table 2.1, associated pollution is also an increasing concern due to the lack of enforceable measures, though it remains a lesser percentage of the contribution to marine debris than land-based sources.[25]

In addition to concerns regarding marine pollution generated by maritime shipping, given that international commerce principally transits the oceans, hazards to navigation such as fouled water intakes and propellers are also a critical ocean transportation issue.

Wealth Production

The final essential ocean function to be addressed is wealth creation, or what the Organization for Economic Co-operation and Development (OECD) refers to as the "ocean economy." In the OECD's 2016 report, *The Ocean Economy in 2030,* the ocean economy is defined as "the sum of the economic activities of ocean-based industries, and the assets, goods and services of marine ecosystems."[26] To better understand this concept, it is useful to separate the ocean economy into three categories: established, emerging and future. The established ocean economy is that which has been in existence for a suitable period of time and thus is commonly recognized and accepted. This is broadly defined as "encompass[ing] shipping, shipbuilding and marine equipment, capture fisheries and fish processing, maritime and coastal tourism, conventional offshore oil and gas exploration and production, dredging,

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[24] Klages, Lars, and Melanie, *Marine Anthropogenic Litter*, 14-15.

[25] Judith S. Weis, *Marine Pollution: What Everyone Needs to Know* (New York: Oxford University Press, 2015), 42.

[26] José Ángel Gurría Treviño, "The Ocean Economy in 2030," (Organization for Economic Co-operation and Development, 2016), 22.

and port facilities and handling."[27] Emerging ocean industries also contribute to the ocean economy and include those that are gaining recognition such as "offshore wind, tidal and wave energy; offshore extraction of oil and gas in deep-sea and other extreme locations; seabed mining for metals and minerals; marine aquaculture; marine biotechnology; ocean monitoring, control and surveillance."[28] Finally, the future ocean economy also includes consideration of ocean economic possibilities such as "carbon capture and storage (CCS) and the management of ocean scale protected areas."[29]

It is difficult to quantify the actual wealth derived from the ocean due to varying state and international accounting and reporting practices and due to the volume of illegal, unregulated and unreported fish catches; however, efforts have been made to reasonably determine the value of the established ocean economy. One well-documented study calculated the Gross Marine Product (GMP), or the ocean's annual economic value similar to a country's Gross Domestic Product (GDP), to be more than US $2.5T.[30] If the ocean's GMP were to be considered a country, the ocean would have "the 7th largest economy in the entire world"[31] as indicated in Figure 2.3. As an example, in the single category of fishing for human consumption, the industry had an estimated value of "$160.2 billion USD in 2014."[32]

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[27] Ibid., 18.

[28] Ibid.

[29] Ibid., 18.

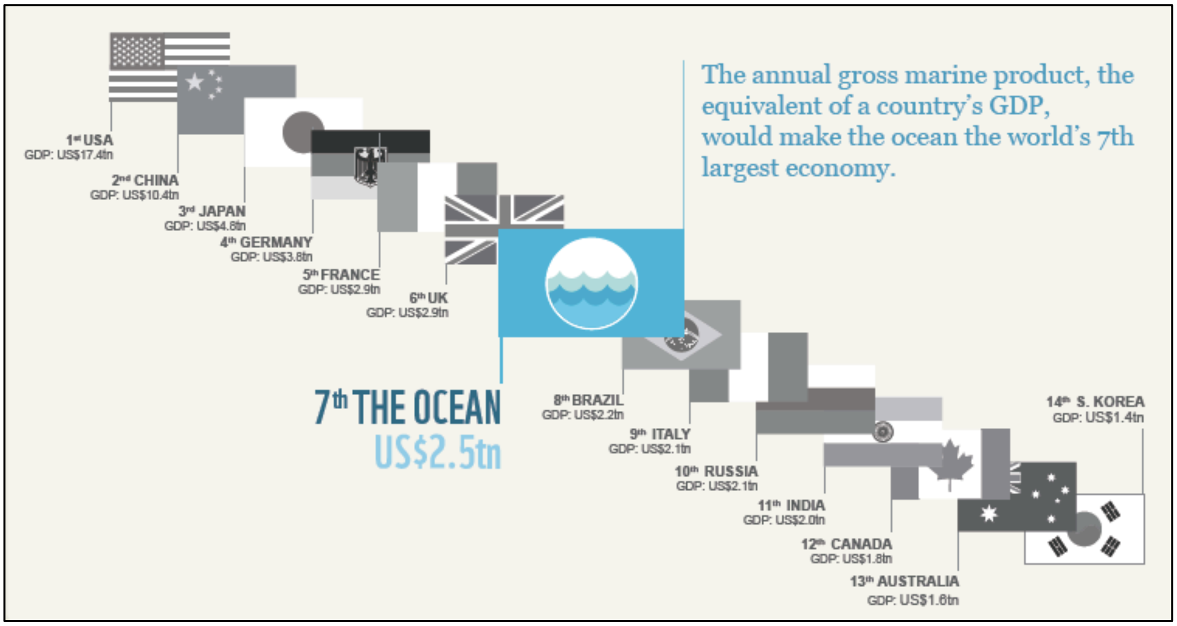
[30] O. Hoegh-Guldberg, "Reviving the Ocean Economy: The Case for Action - 2015," (Geneva, 2015), 7.

[31] Ibid.

[32] Food and Agriculture Organization of the United Nations, "The State of World Fisheries and Aquaculture (2016) - Contributing to Food Security and Nutrition for All," 5-6.

Figure 2.3

Annual Gross Marine Product



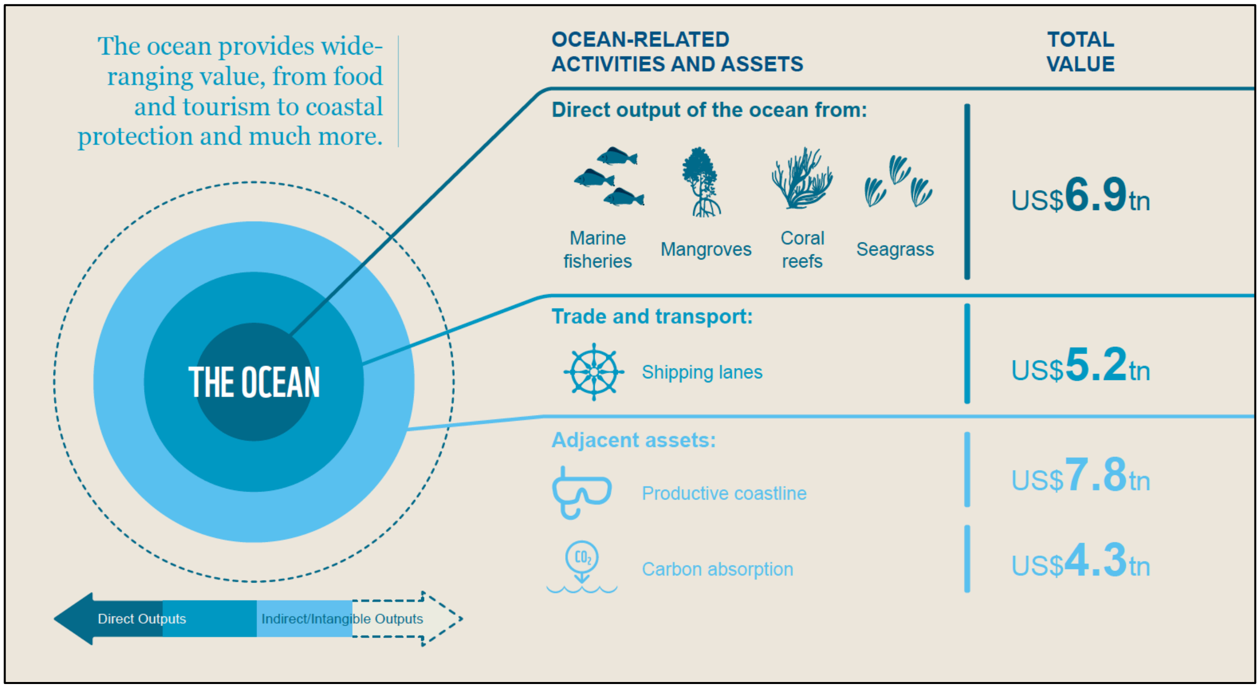
Source: *Reviving the Ocean Economy: The Case for Action – 2015* (Geneva WWF International)[33]

While the GMP represents a minimum annual estimate, the overall global asset value which includes harvesting ocean nutrition, trade and transport, coastal livelihoods, recreational activities and carbon absorption has been approximated to be more than US $24T as indicated in Figure 2.4.

[33] Hoegh-Guldberg, "Reviving the Ocean Economy: The Case for Action - 2015," 14.

Figure 2.4

Global Ocean Asset Value



Source: *Reviving the Ocean Economy: the case for action – 2015* (Geneva WWF International)[34]

The assessments associated with Figures 2.3 and 2.4 do not include intangibles or non-market values such as water filtration conducted by wetlands and seagrass, known as ecosystem services.[35] Absent a comprehensive approach for valuing ocean related intangibles, it is reasonable to assume that the values currently available offer a deceptively low estimate of the ocean's economy.

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[34] Ibid.

[35] Ibid., 13.

Ocean Contamination and Degradation

Post-Industrial Revolution Growth

With an ever-increasing global human population, production and consumption, in both developed and developing countries, has been on a steep and steady climb since the Industrial Revolution. An unpleasant but nonetheless important by-product of this historically unprecedented production and consumption is voluminous amounts of anthropogenic waste. By some estimates, waste production has grown more than tenfold in the past century and, according to a 2018 World Bank Group report, more than 2 billion tons of solid waste was globally generated in 2016.[36] Given the current pace of population and growth, coupled with production and consumption, the report estimates waste production will increase to 3.4 billion tons by 2050.[37] In the past century, as the world's population has grown and become more urban, a dramatic increase in waste generation has resulted. At the beginning of the 20th century, there were approximately 220 million urban residents, representing roughly 13 percent of the global population, which produced less than 300,000 tons of solid waste per day. By 2000 the urban population had risen to approximately 2.9 billion people, representing roughly 50 percent of the global population, and was generating over 3 million tons of solid waste per day (Figure 2.5).[38]

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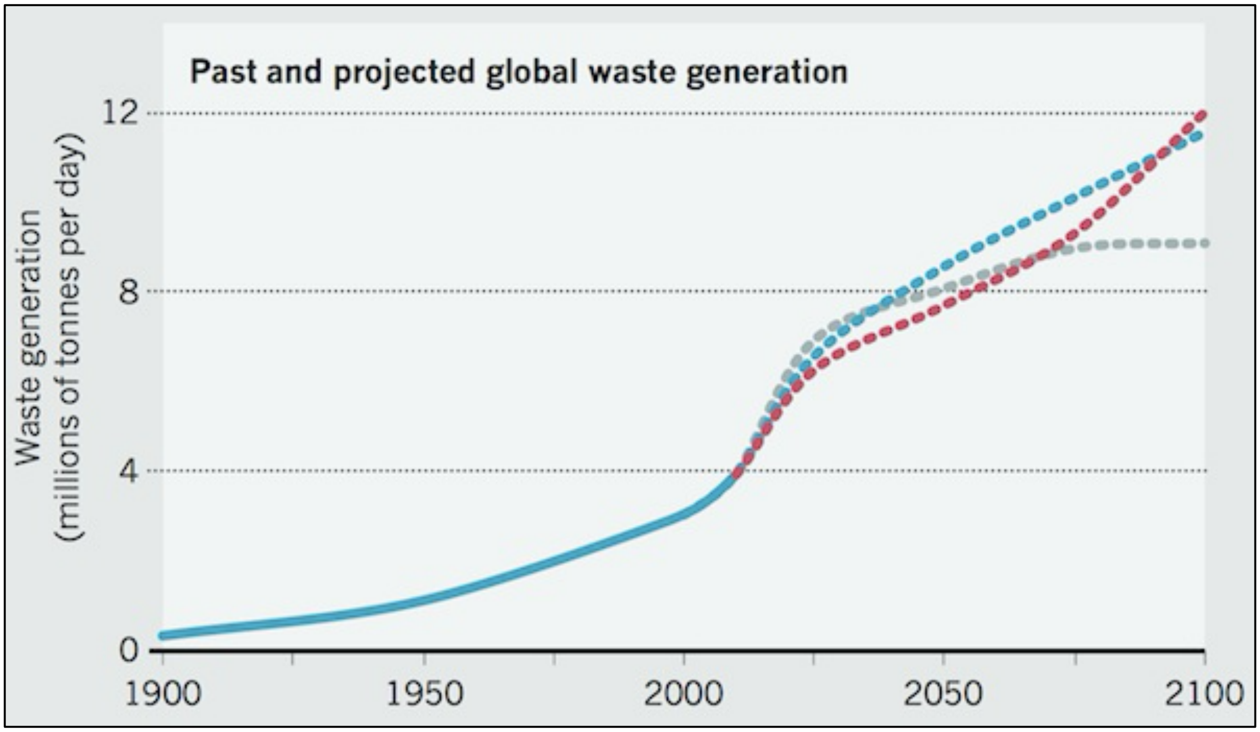
[36] Silpa Kaza et al., *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*, Urban Development Series (Washington DC: The World Bank, 2018), 18.

[37] Ibid., 24.

[38] Daniel Hoornweg, Perinaz Bhada-Tata, and Chris Kennedy, "Environment: Waste Production Must Peak This Century," *Nature* 502, no. 7473 (2013): 616.

Figure 2.5

Past and Projected Global Waste Generation



Graph indicates three modeled peak waste production points. The dotted grey line represents concerted efforts by urban populations to reduce fossil fuel consumption and heighten environmental consciousness.
Source: Hoornweg, Daniel, Perinaz Bhada-Tata and Chris Kennedy, "Waste Production Must Peak this Century"[39]

Post-Industrial Revolution production- and consumption-related waste generation is reaching levels so significant that it has garnered international attention, most notably in carbon emissions' influence on climate change but also in several other areas such as the expansion of a global waste trade and the growing concern with plastic waste. These issues are directly linked to ocean contamination through ocean acidification, pollution, and marine debris - all

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[39] Ibid.

which present both hazardous environmental and human health impacts.

Ocean Warming

Following growing concern regarding global warming and climate change, the International Panel on Climate Change (IPCC) was created in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to aid governments in developing climate policy. In order to distinguish between the two, global warming is defined as the average increase in temperature of the earth's (and ocean's) surface; whereas, climate change is defined as a change in the mean climate over an extended period (typically decades or longer.)[40]

When contemplating the ocean, one of the most important aspects to consider is that the ocean's temperature is fundamentally an index for the state of the global climate. The ocean is the largest factor in the climate system, absorbing and storing roughly 90 percent of the earth's heat it is unable to reflect into space, and thus the ocean's surface temperature regulates and establishes the sea-level atmosphere through alteration of currents, and directly affects the climate zone where humans live. Second, ocean temperature controls evaporation from the sea surface: the warmer the sea surface is, the more evaporation occurs leading to a more intense hydrological cycle (the more water that enters the atmosphere, the more water falls out of the atmosphere – increasing rainfall and severe storms). Finally, sea-level rise occurs as a result of both the warming and expansion of sea water, as well as the melting of ice.

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[40] "IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change," 216.

In addition to the climate and sea-level rise impacts of ocean warming, there are also significant impacts within the subsurface ocean ecosystems.

Fisheries are negatively affected by the warming ocean as increased temperatures force migration to waters with more tolerable temperature limits and better breeding grounds, though the new waters may not have the necessary elements for long-term sustainability found in the former fishery ecosystem. This creates concerns for human livelihoods: the 2018 FAO report estimated more than 40 million people rely on ocean fishing as a source for their economic livelihood.[41] Furthermore, “fish provided about 3.2 billion people with almost 20 percent of their average per capita intake of animal protein,”[42] heightening concerns regarding food security. Warmer oceans also affect coral reefs, a diverse ecosystem that provides shelter and habitat for thousands of marine species, while also providing protection from wave action to coastlines and thus preventing erosion. Increased water temperature causes coral bleaching, which is when corals expel algae (their primary food source) from their tissue in order to minimize function and combat stress, essentially creating a state of starvation. This leaves the coral brittle and more susceptible to disease and, if subjected to this environment for an extended period of time, the coral is likely to die. A common example of this phenomenon is that of the Great Barrier Reef off the western coast of Australia which, in recent years, suffered from two major marine heat waves. In 2016 the Great Barrier Reef lost 29 percent of its corals

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[41] Food and Agriculture Organization of the United Nations, "The State of World Fisheries and Aquaculture (2018) - Meeting the Sustainable Development Goals," 30.

[42] Ibid., 70.

and in 2017 it lost another 22 percent as part of a global bleaching event that lasted from 2014-2017.[43] Photo 2.1 provides a representation of three stages of coral reef decline.

Photo 2.1

Coral Bleaching and Death in American Samoa

Source: National Public Radio, Eakin interview on "Here & Now"[44]

Ocean Acidification (Phytoplankton, Coral Reefs, Shellfish)

Ocean acidification is another aspect of ocean contamination and degradation ,and is often confused with ocean warming. As previously mentioned, ocean acidification is a

[43] C. Mark Eakin, interview by National Public Radio "Here & Now", May 9, 2018. Topic of this interview is – "Great Barrier Reef Bleaching 'Has Been Devastating' – But Don't Give Up Hope."

[44] Ibid.

reduction of the pH level of seawater where pH is a figure that expresses the acidity (or alkalinity) of an aqueous solution and is done so on a logarithmic scale from 1 to 14 with 7 representing the neutral point. A pH level of seawater below 7 indicates increasing acidity while numbers higher than 7 represent decreasing acidity. While "average oceanic pH… changes are usually on the order of ~0.002 units per 100 years,"[45] the observed rate of change in the Post-Industrial Revolution is ~0.1 units, or approximately 50 times faster. This is not only concerning as a general statistic but it indicates "a more rapid change than any other known change in ocean chemistry in the last 50 million years,"[46] and provides a strong indication that even with its immense size, the ocean is not able to maintain pace with the amount of CO^2 produced. According to NOAA, the ocean presently absorbs CO^2 at a rate of "around 22 million tons per day."[47] Given that evolution is generally measured in millions of years, this rapid change in ocean chemistry does not afford marine life appropriate time to adapt.

As a result of increasing ocean acidification, calcifying marine organisms such as corals, mollusks, crustaceans and some plankton are hampered in their production of skeletons and shells. "Coral reefs are the most widely recognized ecosystem threatened by ocean acidification"[48] because it weakens their skeletal structure. Meanwhile, shellfish are also

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[45] "IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change." This reference is from chapter 5, page 19 by M. Rhein, S.R. Rintoul, S. Aoki, et al.

[46] The Ocean Portal Team, "Ocean Acidification," Simthsonian, https://ocean.si.edu/ocean-life/invertebrates/ocean-acidification.

[47] Ibid.

[48] Joan Kleypas and Kimberly Yates, "Coral Reefs and Ocean Acidification," *Oceanography* 22, no. 4 (2009): 109.

subject to the harmful effects of ocean acidification. Hard-shelled jointed crustacea which include seafood like shrimp, crab and lobster, as well as mollusks (soft-bodied invertebrates that exist within a hinged hard shell) like oysters, clams, mussels and scallops, are all threatened by damage from acidification to the calcium carbonate that forms their shells. Furthermore, in a 2015 study of ocean acidification to explore how it might impact phytoplankton, researchers determined that ocean acidification will increase greatly, so much so that by 2100 some species of phytoplankton will likely have become extinct. This raises grave concern bearing in mind many other marine species depend on phytoplankton as their food source and it is also a major source of global CO^2 – O^2 conversion. The study signals a strong warning of the impact ocean acidification will have on the delicate balance of marine habitats and ecosystems.[49]

Pollution

There are two principal types of water pollution - single source and diffused pollutants. A single source pollutant, also known as point source, originates from one identifiable source, localized and traceable to its origin, which is often a pipe or an oil spill. A diffused pollutant, also known as a non-point source, is not easily attributed to one source and can be associated with various types of marine debris. Single source pollutants such as oil, gas, and chemicals other than solid debris have various single sources, the most recognized are major ship or oil rig accidents but much of this type of pollution is actually due to human carelessness or mismanagement of oil products resulting in drainage from land-based origins or unregulated

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[49] Stephanie Dutkiewicz et al., "Impact of Ocean Acidification on the Structure of Future Phytoplankton Communities," *Nature Climate Change* 5, no. 11 (2015): 1002.

recreational boating. According to the National Research Council's *Oil in the Seas III* of 2003, pollution from the consumption of petroleum from all means including cars, boat and runoff from urban areas "contribute[s] the vast majority of petroleum introduced to the environment through human activity."[50] This equates to an estimated 480,000 tons (140,000,000 gallons) worldwide each year of consumed petroleum (or nearly 70 percent of the global total) with the balance associated with routine maintenance of commercial ships, particles from air pollutants and natural seepage from the seafloor.

Pollution damages the marine environment by upsetting the natural balance of the ocean's ecosystems. In order to better understand the impact of such a pollutant in our ocean, consider that "oil destroys the insulating ability of fur-bearing mammals, such as sea otters, and the water repellency of a bird's feathers, thus exposing these creatures to the harsh elements. Without the ability to repel water and insulate from the cold water, birds and mammals will die from hypothermia."[51] Not only does oil have an external impact, but many of these same animals will be poisoned from ingesting oil. Additionally, fish and shellfish are also at risk should they come into contact with oil mixed into the water column: "when exposed to oil, adult fish may experience reduced growth, enlarged livers, changes in heart and respiration rates, fin erosion, and reproduction impairment."[52]

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[50] National Research Council, *Oil in the Seas III* (Washington DC, : National Academic Press, 2003), 3.

[51] National Ocean Service National Oceanic and Atmospheric Administration, "How Does Oil Impact Marine Life?," National Oceanic and Atmospheric Administration, https://oceanservice.noaa.gov/facts/oilimpacts.html.

[52] Ibid.

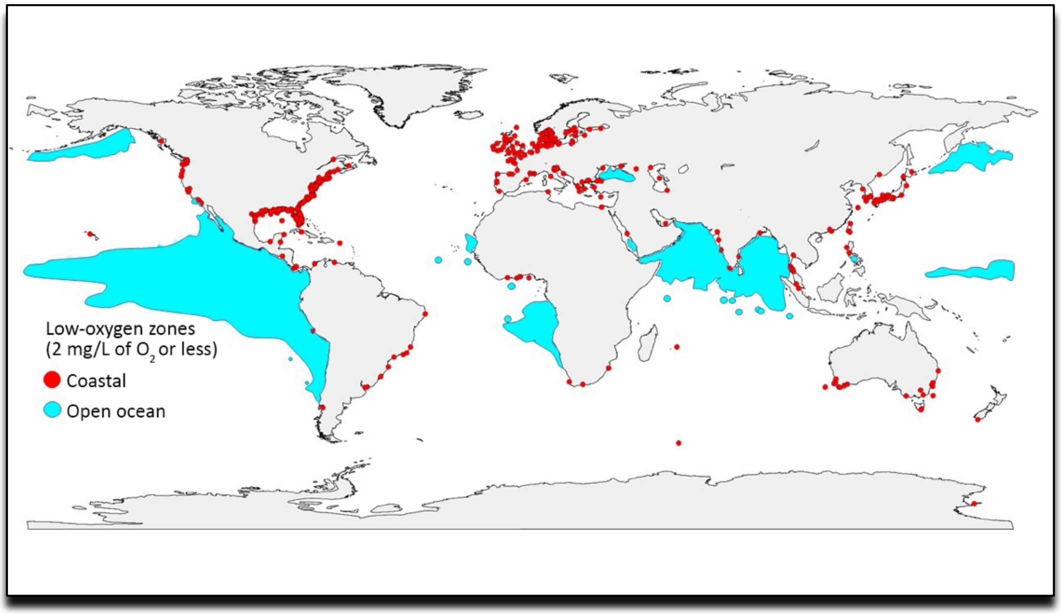
Runoff is also another form of pollution which has resulted in an increasing concern for the ocean in the context of "dead zones." Dead zones occur when levels of oxygen are significantly reduced in the water creating a state of hypoxia and making the area unsurvivable for most marine life, even fostering the collapse of some ocean ecosystems. When excess nutrients are piped as wastewater or run off land into rivers and coasts, they promote an immense amount of algae growth. The algae eventually die, sink and decompose, consuming oxygen that would normally be supplied to other marine life in that ecosystem. [53] While this can occur naturally, human activity can exacerbate the process. Take, for instance, sewage or agricultural effluent such as animal waste and fertilizer which is often deposited in coastal waters. According to the United Nations Educational, Scientific and Cultural Organization's (UNESCO) Intergovernmental Oceanographic Commission (IOC), this effluent contributes to an estimated "500 dead zones covering more than 245,000 km^2 globally, equivalent to the surface of the United Kingdom."[54] These areas are broadly represented in Figure 2.6.

[53] National Ocean Service National Oceanic and Atmospheric Administration, "What Is a Dead Zone?," https://oceanservice.noaa.gov/facts/deadzone.html.

[54] United Nations Educational, "UNESCO: Building Equitable, Inclusive, Green Societies".

Figure 2.6

Distribution of Hypoxic Oceanic Areas



Source: GO2NE Working Group, IOC-UNESCO. Data from World Ocean Atlas 2013. https://en.unesco.org/go2ne[55]

While the direct effects of ocean acidification and pollution are alarming, the broader implications are even more grave. The impacts of these issues are not limited to the examples that have been provided, they extend up the food chain and negatively affect global health and economic activities.

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[55] For more recent literature of coastal dead zones an excellent reference is C. Sheppard, *World Seas: An Environmental Evaluation Volume III: Ecological Issues and Environmental Impacts* (Elsevier Ltd., 2019). Chapter 24, Dead Zones: Oxygen Depletion in Coastal Ecosystems by Andrew H. Altieri and Robert J. Diaz address this topic with detailed graphics. Graphic representations from this literature were not utilized for the purposes of this project only due to their coastal focus; Figure 2.6 provides a more holistic image.

Marine Debris

Marine debris is anthropogenic waste defined as "any persistent, manufactured, or processed solid material that is directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment."[56] The ocean not only provides the bulk of the global oxygen, regulates climate, houses a major source of protein for human consumption, provides the transportation avenue for the bulk of global commerce and supports a substantial amount of the global economy, but it is also the repository for an untold volume of tires, cardboard boxes, shipping containers, cans, plastic bags and bottles, and other trash that forms the general components of marine debris.

Marine debris is a newer category of pollution which has been generally recognized as a problem only in the past 50 years. Its volume is much more difficult to measure. Marine debris not only floats on the surface in various sizes and forms but is also found on beaches, below the surface and on the seafloor. While debris such as lost shipping containers and other heavy materials often sinks to the ocean floor, large plastics, Styrofoam and some fishing nets are found on the surface. The vast majority of this debris is believed to be light and small making it vulnerable to being caught in underwater currents which perpetuates drift of debris that travels throughout the water column. In fact, debris is now believed to permeate the entire water column from surface to ocean floor across the entire ocean and through the majority of global rivers. Since the ocean is in constant motion due to wind and currents, marine debris is also in motion, compounding the difficulty in making accurate determinations of the volume of marine

[56] National Research Council, *Tackling Marine Debris in the 21st Century* (Washington DC: National Academies Press, 2009), 17.

debris both in any specific location or across the entire ocean.

Marine debris is most notably associated with “garbage patches,” first discovered in 1997 by Captain Charles Moore of the Algalita Marine Research Foundation while sailing across the Northern Pacific Ocean from Hawaii to California. He came upon a depressing sight of floating garbage through which he would continue to sail for a week, covering hundreds of miles.[57] Globally, there are five garbage patches bounded by the five major ocean gyres (Figure 2.7), composed of vortices of circular ocean currents resulting from the forces created by the rotation of the planet and its wind patterns. Their circular motion, clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere, draws debris into a stable center, where it becomes trapped. The largest and most recognized of these is Captain Moore’s Great Pacific Garbage Patch, located in the eastern portion of the North Pacific Subtropical Gyre, and while estimates vary, Lebreton et al (2018) indicate upwards of 79,000 tons of plastic was floating in this area of approximately 1.6 million square kilometers, often referenced to be twice the size of Texas.[58] Due to the unbounded nature of debris in these gyres and the ocean in general, it has been suggested that Captain Moore, by pure chance, had inadvertently “stumbled across the twenty-first-century Leviathan. It had no head, no tail. Just an endless body.”[59]

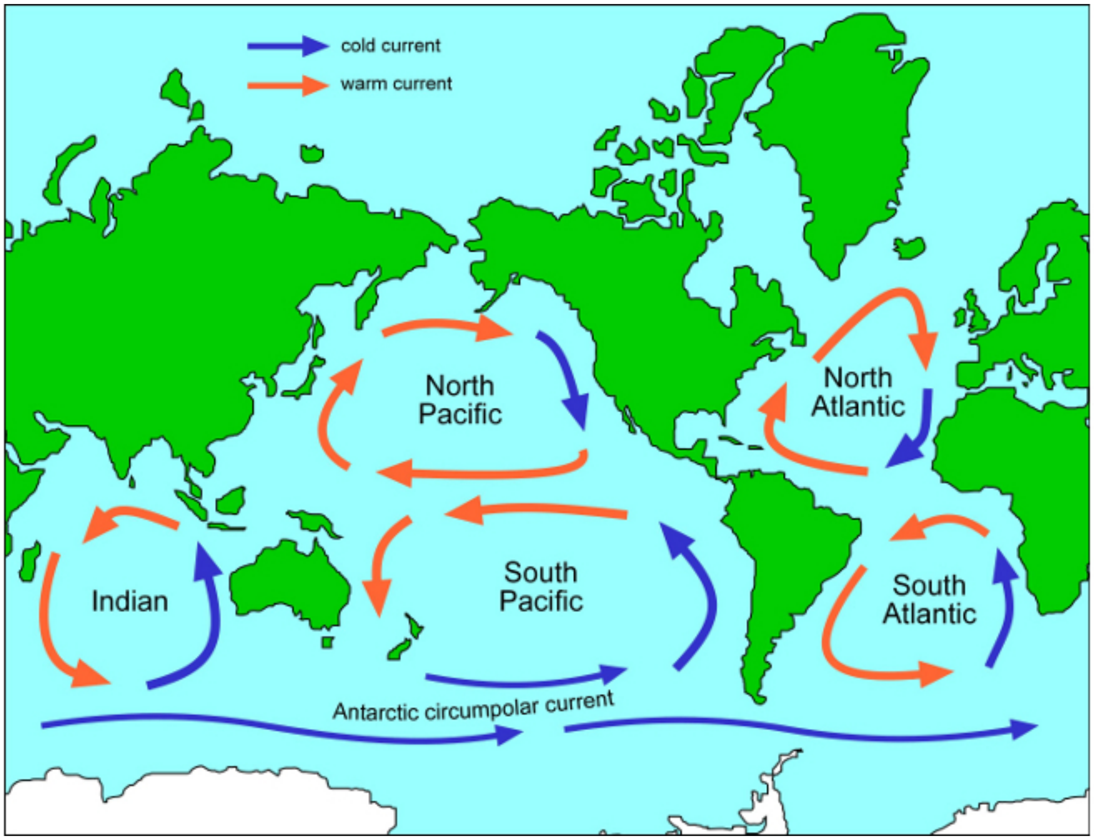
[57] Susan Casey, "Garbage in Garbage Out," *Conservation Magazine* 11, no. 1 (2010): 14.

[58] Ibid. Also referenced in Kate O’Neill, *Waste* (Medford, MA: Polity Press, 2019).

[59] Casey, "Garbage in Garbage Out," 13.

Figure 2.7

Five Ocean Gyres and Their Circulation Patterns



Source: Science Learning Hub – Pokapū Akoranga Pūtaiao, Government of New Zealand[60]

Marine debris is not limited to what we can see floating in ocean gyres. Tires, artificial reefs and numerous other elements contribute to marine debris. Ghost fishing, a phenomenon where abandoned fishing gear such as gillnets and crab pots continue to trap fish and other marine animals and organisms indefinitely, is estimated to impact over 200 species

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[60] Science Learning Hub - Pokapū Akoranga Pūtaiao, "Ocean Motion," https://www.sciencelearn.org.nz/resources/691-ocean-motion. Science Learning Hub is a cooperative initiative between the New Zealand Government and The Waikato University.

worldwide.[61] As a small and select example, in their 2014 study, Uhrin, Matthews, and Lewis estimated that there were “approximately 85,000 ghost fishing traps,” [62] more specifically lobster and crab traps, in the Florida Keys National Marine Sanctuary. While nets were traditionally made of biodegradable material, a shift to more durable plastic and vinyl-coated steel occurred in the mid-1970s and early 1980s. Consequently, the occurrence of entanglement and prolonged existence of abandoned fishing gear has increased (Photo 2.2). This added volume of marine debris not only entangles marine animals, it also fouls commercial shipping gear and damages systems and hardware.

[61] National Oceanic and Atmospheric Administration, "2014 Report on the Entanglement of Marine Species in Marine Debris with an Emphasis on Species in the United States," (Silver Spring,: NOAA, 2014), 16.

[62] Amy V. Uhrin, Thomas R. Matthews, and Cynthia Lewis, "Lobster Trap Debris in the Florida Keys National Marine Sanctuary: Distribution, Abundance, Density, and Patterns of Accumulation," *Marine and Coastal Fisheries* 6, no. 1 (2014): 27.

Photo 2.2

Ghost Fishing

A dead tiger shark (and other fish) entangled in derelict nets in Florida
Source: NOAA Report, *2014 Report on the Entanglement of Marine Species in Marine Debris with an Emphasis on Species in the United States."*[63] Photo by Elaine Blume[64]

In the second half of the 20th century, it became acceptable to many countries, including the United States, Japan, France, Spain, Portugal, Italy, Malaysia and Israel, to dump millions of tires and sink derelict ships as "innovative" ways to create artificial reefs. Unforeseen was the

[63] National Oceanic and Atmospheric Administration, "2014 Report on the Entanglement of Marine Species in Marine Debris with an Emphasis on Species in the United States," 15.

[64] Ibid.

environmental damage and marine degradation these efforts would generate. While some of the ships were extensively stripped and environmentally cleaned, resulting in a few thriving artificial reefs, more of these initiatives caused extensive harm to the marine environment. In recent years, both public and private initiatives in Florida have been underway to clean up these intentional ocean dump sites and one example is that a military divers retrieving tires from the ocean floor shown in Photo 2.3.

Photo 2.3

US Military Divers Removing Tire Waste

Source: South Florida Sun Sentinel [65]

[65] David Fleshler, "Military Divers to Help Clear Undersea Tires in Fort Lauderdale," *South Florida Sun Sentinel*, December 19, 2011.

While it is difficult to quantify the volume of debris in the ocean due to its unbounded nature and constant motion from winds and ocean currents, research studies as well as international organizations are increasingly determined to accurately assess the issue. In 1975, the National Academy of Sciences estimated that 14 billion pounds of garbage was being dumped into the ocean every year; however, more recent revisions of that estimation have been scarce. One of the few published reports from a team of experts for the United Nations in 2016, *First Global Integrated Marine Assessment,* estimates "that the average density of marine debris varies between 13,000 and 18,000 pieces per square kilometer."[66] While estimating the volume of all marine debris is difficult, there is a growing consensus that the majority of marine debris is composed of plastics whose volume is growing rapidly.

Plastic

The growing literature on marine debris tends to focus on one aspect - plastics. This is in large part due to the simple fact that plastics are the most prevalent debris item and are estimated to contribute up to 80 percent of all marine debris.[67] In 2006, the UNEP estimated that every square mile of ocean contains 46,000 pieces of floating plastic.[68] While the exact volume is difficult to determine, the single category of "plastic on the open ocean surface was

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[66] Lorna Inniss and Alan Simcock, "The First Global Integrated Marine Assessment: World Ocean Assessment I," (United Nations Division for Ocean Affairs and the Law of the Sea, 2016). More specifically, this is found in Part 1, Section F.

[67] Ibid., 29.

[68] UNESCO United Nations, "Building Equitable, Inclusive, Green Societies," http://www.unesco.org/new/en/natural-sciences/ioc-oceans/focus-areas/rio-20-ocean/blueprint-for-the-future-we-want/marine-pollution/facts-and-figures-on-marine-pollution/.

estimated to be on the order of tens of thousands of tons"[69] and the 2018 PEW Report, *Preventing Ocean Plastics*, estimated close to "13 million metric tons of plastic enter the ocean each year."[70] It is disturbing to realize the magnitude of the problem: phytoplankton, the major O^2 producer, is a subset of plankton and in the most polluted places in the ocean, plastic exceeds the amount plankton six times over posing a significant threat to our O^2 generation.[71]

Plastic, in the form of rubber, is a natural product originating from gumtree sap; however, with the development of synthetic plastic in the mid-19th and early -20th centuries, a number of plastic variations came into circulation. Coupled with this development, a less expensive, highly industrialized, relatively easy means of production was introduced, enabling rubber/plastic production on a mass scale in the early 1950s. Plastics are made of polymers which are long flexible chains of chemical compounds. Polymers are generally lightweight which allows plastic to be easily molded and shaped, especially under the combination of heat and pressure. Furthermore, most modern plastic is human-made and derived from fossil fuels with crude oil and natural gases functioning as the primary source materials.

A product of the 20th century's demand for cheap, lightweight and durable goods, plastic was mass-manufactured and globally consumed by the ton without consideration for its eventual disposal. Current global production exceeds 300 Mt per year. The production and use of plastic is so voluminous that it is ubiquitous in most every aspect of modern life: if not consumed as a plastic container, wrapper or tool, it is quite likely to be found in other materials

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[69] Andrés Cózar et al., "Plastic Debris in the Open Ocean," *pnas.org* 111, no. 28 (2014): 1.

[70] PEW Charitable Trust, "Preventing Ocean Plastics," https://www.pewtrusts.org/en/projects/preventing-ocean-plastics.

[71] Casey, "Garbage in Garbage Out," 14.

such as man-made fibers, mobile phones and cigarette butts. A disturbing fact about human-made fibers (known as acrylic, microfiber, polyester and the more obvious nylon) is that every time these fibers are washed, tiny microplastics rub off and travel into the water system.

Many plastic products fall into a category defined as single-use plastic: used one time, for less than a minute in some cases, then discarded, often without further consideration. To illustrate the stunning volume of this limited use commodity, consider that roughly "330 billion single-use plastic carrier bags are produced every year – that is over 10,000 bags per second."[72] A similar single-use example is common beverage bottles which "are a major plastic packaging application, representing at least 16% of the market (by weight)."[73] The magnitude of this problem starts to take shape given that "only 14% of plastic packaging is collected for recycling globally."[74]

In their 2012 article, Lebreton, Greer and Borrero claimed consumption of plastic in North America and Western Europe, for 2007, to be 100 kg per capita and estimated that number to reach 140 kg per capita by 2015. They further cite Plastinum's (2009) estimate that "global production of plastics has increased by 500% over the last 30 years, while consumption per capita has increased by over 50% in the last decade." Additionally, they cite Shen et al (2009) who predicted global plastic production will "reach 850 million tons per year" by 2050.[75]

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[72] Ellen MacArthur et al., "The New Plastics Economy: Catalysing Action," (Geneva: World Economic Forum, 2017), 30.

[73] Ibid., 21.

[74] Ibid., 23.

[75] L. C. M. Lebreton, S. D. Greer, and J. C. Borrero, "Numerical Modelling of Floating Debris in the World's Oceans," *Marine Pollution Bulletin* 64, no. 3 (2012): 654.

According to Lebreton et al, the western portion of "Europe produces around 500 kg of household waste per capita, the US around 750 kg and the developed world around 100 kg per year."[76] They also suggest that in developing countries, plastic consumption is increasing rapidly, while creating infrastructure for waste management and promoting environmental awareness are not. With the increasing production and consumption of plastic both in developed and developing countries, measures to reduce and recycle are crucial.

Plastics are not biodegradable, nor can they be melted or incinerated without significant environmental impacts from carbon and toxic emissions. Due to factors such as durability and low recycling rates, plastics not only accumulate in landfills (according to Plastinum (2009), in 2006, 11.5 Mt of plastic were dumped into landfills) but enter the marine environment and persist in marine ecosystems. Common means of entry into the marine environment include: ocean dumping; shipping and fishing activity; coastal litter that is swept into the ocean by the tides; and garbage bags, plastic bottles, wrappers, cup lids and straws that are washed or blown into inland waterways and then carried out to sea.[77] As a result, the volume in the ocean is such that a 2015 Science article by Jambeck et al estimated that "plastic waste entering the ocean is one to three orders of magnitude greater than the reported mass of floating plastic debris in high-concentration ocean gyres and also globally."[78] Furthermore, plastics' tendency to sorb (take up) persistent, bioaccumulative, and toxic substances, results in

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[76] Ibid.

[77] Laurent C. M. Lebreton et al., "River Plastic Emissions to the World's Oceans," *Nature Communications* (2017): 2.

[78] Jenna R. Jambeck et al., "Plastic Waste Inputs from Land into the Ocean," *Science* 347, no. 6223 (2015): 770.

"trace quantities in almost all water bodies."[79]

Plastics' pervasiveness in the marine environment is enhanced by its unbounded nature: it floats on the surface in myriad shapes and sizes; it drifts through the water column freely moving with currents' circular and vertical movements; it collects on the seafloor, even disappearing under layers of sediment over time. Evidence from scientific sampling, as well as from commercial and recreational activities, has confirmed the existence of plastics not only throughout the water column and on the seafloor but in Antarctic ice samples - strongly suggesting no portion of the ocean is untouched by plastic debris.

The impact of marine plastic is vast. Mainstream media is increasingly carrying news stories that cover life-threatening struggles and horrific deaths of sea turtles, marine birds, whales, dolphins, fish and seals. One of the most common causes of death among marine animals results from ingesting plastics. Marine animals often mistake plastic as a food source, swallowing the plastic items as they would any other meal of similar size and shape. For example, sea turtles mistake plastic shopping bags floating in the sea column for their favorite food – jelly fish. They grab and swallow the bags which are then trapped by hundreds of barb-like spines called "papillae" that line the esophagus in a downward facing direction. Like food, bags are prevented from escaping while water is expelled which can eventually lead to starvation and death (Photo 2.4).

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[79] Nate Seltenrich, "New Link in the Food Chain?," *Environmental Health Perspectives* 123, no. 2 (2015): A35.

Photo 2.4

Dead Sea Turtle with Partially Ingested Plastic Bag

Source: Public Domain[80]

One of the more recognized stories, carried by the global media, was in November 2018 of a dead sperm whale found washed ashore off Kapota Island in the Wakatobi National Park in Indonesia. According to reports from the World Wildlife Fund in Indonesia, the 30-plus foot whale was estimated to have more than 1000 pieces of plastic inside including more than 100 cups, 25 bags, bottles, flip flops and other such items weighing more than 13 pounds (Photo 2.5). Stories and accompanying images help convey the devasting impact of plastics on the

[80] Kristin Hugo, "We Are Destroying Sea Turtles with All Our Plastic Waste," *Newsweek*, December 19, 2017.

marine environment.[81] Notably, in the past year several incidents of whale deaths related to large ingestion of plastics have become widely reported.

Photo 2.5

Dead Sperm Whale with 13+ Pounds of Ingested Plastic

Source of both photos: World Wildlife Fund – Indonesia, Public Domain[82]

Marine birds are also extremely susceptible to death by ingestion of plastic and other marine debris. Researchers on Midway Atoll routinely find sights such as that in Photo 2.6. Sea

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[81] Laura Parker, "Sperm Whale Found Dead with 13 Pounds of Plastic in Its Stomach," National Geographic, https://www.nationalgeographic.com/environment/2018/11/dead-sperm-whale-filled-with-plastic-trash-indonesia/.

[82] Photos were sourced from the public domain with attribution to the Indonesian World Wildlife Fund.

faring birds mistake a multitude of marine debris, much of it plastic, for edible food sources. Unfortunately, their digestive system is unable to process the debris and death occurs.

Photo 2.6

Dead Albatross on Midway Atoll

Source: A film by Chris Jordan – "The Albatrosses of Midway." [83]

Similar to the dangers of ghost fishing, plastics threaten marine life in terms of entanglement. From plastic bags to portions of plastic bottles, marine debris hinders animals

[83] Chris Jordan, "The Albatrosses of Midway," (The Sierra Club, 2017). This film was originally accessed on The Sierra Club's website; however, it no longer appears to be available at that site. It can be accessed on Chris Jordan's Vimeo site at https://vimeo.com/264508490.

and organisms by entangling fins, flippers and legs. Ensnaring or trapping the animal often suffocates it by constricting its airway or preventing it from moving as shown in Photo 2.7.

Photo 2.7

Plastic Constriction

Source: Public Domain[84]

Mangroves, salt marshes, and marine plants are also highly susceptible to the dangers of plastics. A very dynamic ecosystem, mangroves support flora and fauna and act as a vital nursery to the fish and crustaceans that compose a large portion of the commercial fishing industry. Similarly, salt marshes also stabilize shorelines and filter pollutants. Meanwhile, marine plants such as kelp both nourish and protect many marine organisms. Yet, plastics and other marine debris that infiltrate these ecosystems can severely damage the plants by constricting and breaking branches, while toxins emitted from the breakdown of plastics poison

[84] Both of these photos are found in the public domain. The first is attributed to "picture-alliance/Photoshot/Balance/ANT Photo Library" and the second to "Karen Doody/Stocktrek Images."

the plants. Both processes damage the filtering and protection system that ensures a balanced ecosystem.

More directly affecting human actors – and therefore garnering more immediate attention - is the effect of marine debris on commercial shipping and tourism's recreational boating/diving. Shipping is increasingly vulnerable since floating plastics and other marine debris can foul a ship's propeller(s), shaft(s), and water intake valve(s) as well as damage the hull of the vessel. Similar incidents threaten boats and recreational divers in the tourism industry. Furthermore, enjoyable diving experiences are diminished when divers find themselves encountering plastic waste. These issues can have both costly and dangerous outcomes and can significantly impede a company's economic bottom line.

Finally, because plastics tend to leach toxins as they break down, they present serious water quality concerns that affect human health and safety. They are also likely to contain residual materials which provide a bed that promotes the growth of bacteria. The growing presence of bacterial contamination including E. coli, viruses, neurotoxins and heavy metals found in these polluted waters creates significant health and safety concerns. Consumption of or contact with water polluted with these contaminants and pathogens can result in infectious hepatitis, diarrhea, bacillary dysentery, skin rashes, and even typhoid and cholera.[85]

In 2014, Cózar and his team conducted extensive oceanic microplastic research and "sampled surface plastic pollution at 141 sites across the oceans."[86] They found less plastic

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[85] S. Sheavly and K. Register, "Marine Debris & Plastics: Environmental Concerns, Sources, Impacts and Solutions," *Journal of Polymers & the Environment* 15, no. 4 (2007): 302.

[86] Cózar et al., "Plastic Debris in the Open Ocean," 10243.

than anticipated, yet based on their quantitative analysis, they concluded the amount of plastic in the ocean was not necessarily less than expected. Instead, they suggested that due to breakdown, sinking below detectable depths, and absorption or ingestion by marine organisms, the volume of plastics and microplastics was likely to be significantly higher than detected.[87]

Microplastics

Plastic debris on the ocean surface is deceiving because it is dominated by microplastics (defined by NOAA as pieces of plastic less than 5mm long). Microplastics generally result from the breakdown of larger pieces of plastic (as previously mentioned, plastic is not biodegradable) but some microplastics are manufactured, such as pre-production industrial plastic pellets and "micro-scrubbers" in face wash.[88] As a consequence of their small size and pervasiveness, they are very susceptible to ingestion by marine organisms: in fact, microplastics have been found "in the bodies of dead organisms from fish to birds to whales."[89] In 2015, Cózar's team found that 83 percent of the items collected in the Mediterranean Sea were smaller than 5 mm (e.g. microplastics), and that the estimated volume in that body of water was similar to that in the five garbage patches.[90] This may further support their previous suggestions regarding breakdown of plastics accounting for missing plastics.

[87] Ibid.

[88] National Ocean Service National Oceanic and Atmospheric Administration, Marine Debris Program, Office of Response and Restoration, "Types and Source: What Are Microplastics?," http://marinedebris.noaa.gov/discover-issue/types-and-sources.

[89] Seltenrich, "New Link in the Food Chain?," A37.

[90] Andrés Cózar et al., "Plastic Accumulation in the Mediterranean Sea," *PLoS ONE* 10, no. 4 (2015): 5/12.

Toxins

Plastics are both a consumer and a producer of toxins. They are known to absorb contaminants approximately "one hundred times more efficiently than naturally occurring suspended organic matter."[91] They can easily absorb "heavy metals or resilient poisons like PCBs and DDT which, although banned since the 1970s, still permeates plastic waste today."[92] Plastics also contain toxic chemical additives (released during breakdown) that can dissolve in water or in the digestive systems of living organisms. [93] While conclusive evidence remains scarce, "several studies suggest that some plastic-associated contaminants may be transferred to organisms during digestion, and recent laboratory experiments indicate that plastic-associated contaminants may alter the endocrine system's function of fish."[94] Such alteration to the endocrine system which produces hormones and regulates body function threatens the health of both fish and the human population that consumes them.

As plastics absorb heat from the sun on the surface of the ocean, they become dry and brittle. Combined with the effect of ocean waves and wind, plastics begin to break down - an excellent opportunity for toxins' widespread emission. This phenomenon is compounded by the continuous flow of plastics into the oceans, predominantly from coastal waters and rivers.

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[91] Ibid., 8/12.

[92] Audra Mitchell, "Thinking without the 'Circle': Marine Plastic and Global Ethics," *Political Geography* 47 (2015): 81.

[93] Stephanie L. Wright, Richard C. Thompson, and Tamara S. Galloway, "The Physical Impacts of Microplastics on Marine Organisms: A Review," *Environmental Pollution* 178 (2013): 484.

[94] Cózar et al., "Plastic Accumulation in the Mediterranean Sea," 812.

Coastal Waters and Rivers

According to the IOC, approximately 80% of marine pollution originates on land. Agricultural practices and mining create effluent that contains poisonous chemicals: coastal tourism's petrol residue and litter wash into the ocean; and urban development and manufacturing produce numerous chemicals, debris and sewage that are routinely dumped or blown into rivers which eventually flow into the ocean.

Coastal Waters

The coastline of the world is difficult to measure due to varying scales, but a low estimate is approximately 504,000 kilometers (313,071 miles), 12.5 times the length of the earth's equatorial circumference. This estimate takes into consideration that the ocean is contiguous with more than 190 countries. Moreover, almost 40 per cent of the world's population lives within 100 km (60 miles) of the coast and is likely to be impacted by the health of their coastline. Coastal populations depend on the ocean for commercial fishing, tourism and recreation, shipping and transportation, ports and harbors, and ship and boat building. While they work to care for the health of their coastal waters upon which their livelihood depends, these populations also often contribute to its degradation by dredging harbors, building structural foundations, releasing factory and shipping effluent and carelessly disposing waste.

Oil spills, runoff and other such chemical and soil infiltration threaten coastal waters and create numerous and growing dead zones. This problem is further compounded by coastal waste which comes in several different forms. Plastic is discarded on beaches and conveyed into the ocean by wind and tides. It is tossed into coastal waste bins and because it is often not secured, it is then blown into the coastal waters. Plastic is carelessly dumped into coastal waters by both commercial and recreational vessels. Jambeck et al estimate that approximately "99.5 million MT [metric tons] of plastic waste was generated in coastal regions in 2010."[95]

While the direct impact of coastal debris is notable, the larger concern lies inland where rivers convey the largest amount of debris into the ocean. Coastal regions not only collect debris that originates near the coastline, but they are also the initial repository of effluent from inland rivers.

Rivers

Mismanaged waste is the principal reason plastics are transported via rivers to the ocean. Some plastic is left without regard to where it will end up, other plastic is tossed in unsecured bins where winds blow it into rivers while, similarly, plastic that is conveyed from bins to large dumps can also be caught by winds and carried to nearby rivers. This waste enters "the ocean primarily at coastal release points corresponding to major rivers, cities and urbanized areas."[96] The 2012 seminal study, *River Plastic Emissions to the World's Oceans,* by Lebreton et al "estimated that between 1.15 and 2.41 million tonnes of plastic currently flows from the global riverine system into the oceans every year [Figure 2.8]."[97]

An example of this effluent is plastic bottles, bags and take-out cup lids which are extremely light and commonly found on city streets worldwide. These items are often carried from a street bin on wind currents or on drafts created by passing vehicles and then are blown

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[95] Jambeck et al., "Plastic Waste Inputs from Land into the Ocean," 770.

[96] Lebreton, Greer, and Borrero, "Numerical Modelling of Floating Debris in the World's Oceans," 655.

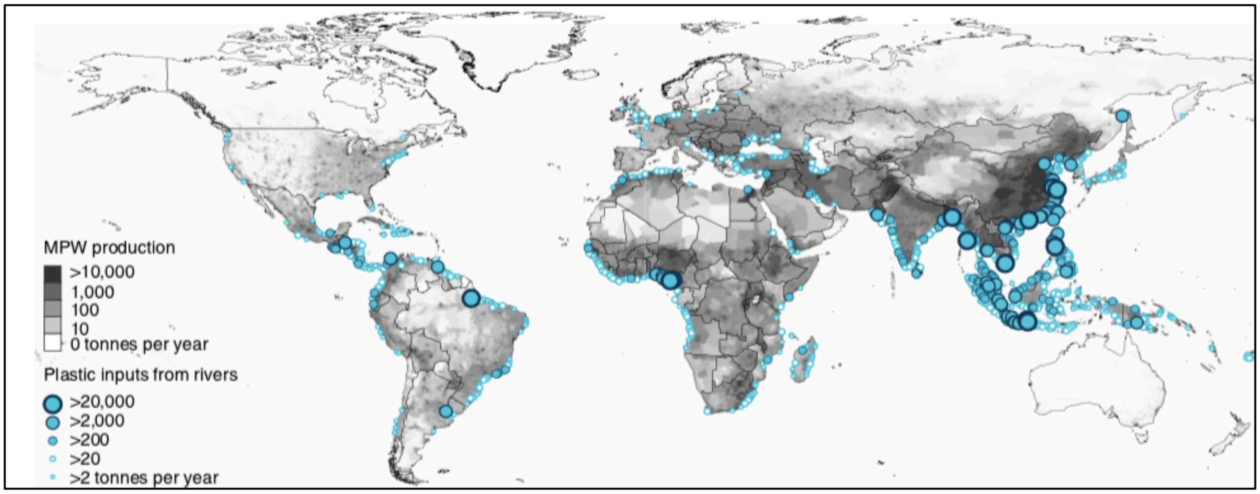
[97] Lebreton et al., "River Plastic Emissions to the World's Oceans," 2.

or washed into the street drainage systems and transported via local waterways to the ocean. Another example is “nurdles” which are tiny pre-production plastic resin pellets created in refineries from oil and gas molecule binding. These small pellets comprise the foundation of plastic products and are generated in various colors, strengths and densities. They are transported in large bags or bins to plastic manufacturing facilities where they are heated and molded into the products purchased by consumers. Nurdles are classified as microplastics whose tiny size contributes to their loss in transport and manufacturing. Further exacerbating the problem is the occurrence of accidental spills: the millions of nurdles released from one overturned truck may end up in roadside sediment or in drainage systems that flow into the ocean bound river system. Numerous recent studies continue to find evidence supporting microplastics invading every aspect of the ocean water column and seafloor, including the Mariana Trench which is the deepest location on the earth at just under seven miles. These microplastics often settle into the sediment of the seafloor and trenches creating an unseen refuse pile of plastics that likely blanket the ocean floor.[98]

[98] A. J. Jamieson et al., "Microplastics and Synthetic Particles Ingested by Deep-Sea Amphipods in Six of the Deepest Marine Ecosystems on Earth," *Royal Society Open Science* 6, no. 180667 (2019): 7.

Figure 2.8

Global Riverine Plastic Flow into the Ocean



Source: *Lebreton et al, "River Plastic Emissions to the World's Oceans."*[99]

Globally, there are approximately 165 major rivers that provide drinking water, food and irrigation, and transport a substantial volume of vessel traffic. Additionally, there are also thousands of smaller rivers with similar attributes. A large portion of these rivers flow into the ocean and most major civilizations and present-day cities have been established on or near rivers.

The top ten rivers contributing marine litter from land-based origins are: Yangtze, Indus, Yellow, Hai, Nile, Ganges, Pearl, Amur, Niger and Mekong:

> "Estimated plastic releases from Asian rivers represented 86% of the total global input. A considerably high-population density combined with relatively large MPW [Mismanaged Plastic Waste] production rates and episodes of heavy rainfalls, resulted

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[99] Lebreton et al., "River Plastic Emissions to the World's Oceans," 2.

> in this dominant contribution from the Asian continent, with an estimated annual input of 1.21 (range 1.00–2.06) million tonnes per year."[100]

For example, the Yangtze River, which flows entirely within China, is the longest river in Asia, the third-longest in the world and one of the largest according to discharge volume. Approximately one-fifth of China's land mass drains into the Yangtze and an estimated 500 million people, more than one third of China's population, live along its river basin and contribute 55 percent of the annual plastic waste flow into the ocean.[101] A graphic representation of the Yangtze's plastic pollution compared to the remaining top ten river polluters is provided in Figure 2.9.

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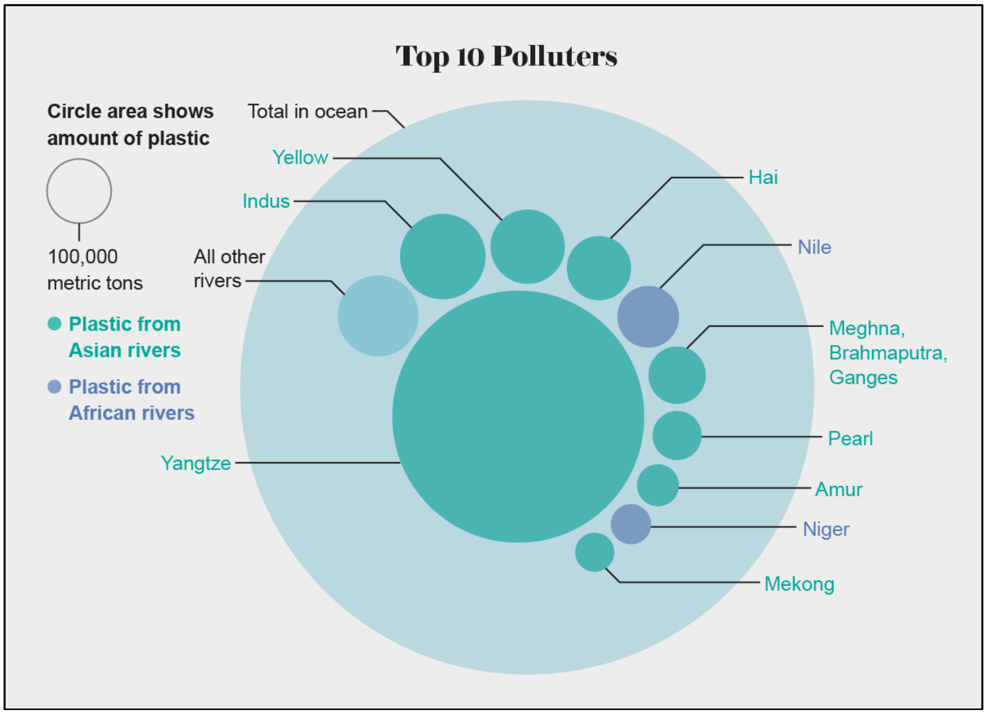
[100] Ibid., 3.

[101] World Bank, "Planet over Plastic: Addressing East Asia's Growing Environmental Crisis," https://www.worldbank.org/en/news/feature/2018/06/08/planet-over-plastic-addressing-east-asias-growing-environmental-crisis.

Figure 2.9

Top Ten Rivers - Plastic Polluters



Credit for graphic: Amanda Montañez[102]

Even though the plastic from the ten largest polluting rivers is significant, it is important not to overlook debris conveyed by coastal pollution or a multitude of smaller rivers. For example, Indonesia, with a population of more than 253 million people, is not home to any of the top ten plastic river polluters, yet it is considered the second highest producer of ocean plastic. This is in large part because Indonesia possesses the third longest coastline in the world

[102] Christian Schmidt, Tobias Krauth, and Stephen Wagner, "Export of Plastic Debris by Rivers into the Sea," *Environmental Science and Technology* 51 (2017). The graphic was sourced from the public domain with attribution to Amanda Montañez. Additional research indicates she derived much of the graphic from material found within this publication.

- 54,720 kilometers (34,000 miles) - due to the numerous islands that make up the country's total coastal area; in contrast, China's coastline is tenth.[103] Indonesia's extensive coastline, formed by more than 17,500 islands (of which more than 6,000 are inhabited), has a coastal population exceeding 187 million, and a large majority of the remaining 66 million reside near rivers. This human proximity to oceanbound water helps explain how Indonesia is the second highest ocean plastic polluter, even though one of the largest polluting rivers is not located in the country.[104] Examples of river pollution are provided in Photos 2.8 and 2.9.

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[103] Central Intelligence Agency, "World Fact Book," https://www.embassyofindonesia.org/index.php/basic-facts/.

[104] Jambeck et al., "Plastic Waste Inputs from Land into the Ocean," 769.

Photo 2.8

Citarum River Pollution

"Collecting plastic rubbish last year for recycling on the Citarum River, the main source of household water for Jakarta, Indonesia."[105]

[105] Photo was sourced from the public domain with attribution to Dadang Tri/Reuters and The New York Times.

Photo 2.9

Ganges River Feeder Pollution

"A worker rummages through plastic waste filling a "river" in the Taimur Nagar district of New Delhi, on June 12, 2018. The waste will be washed away by rains and eventually reach the Indian Ocean through the Ganges River. (Mainichi)"[106] A feeder river to a top ten plastic polluting river.

Given the multiplicity of avenues they afford for plastic conveyance from land-based origins, coastal waters and rivers constitute a major source of plastic flowing into the ocean.

[106] So Matsui and Kosuke Hatta, "From India to Spain, Plastic Waste Becoming a Global Threat to Ecosystems," *The Mainichi*, July 16, 2018.

Conclusion

Our ocean covers almost three quarters of the earth and is critical to the global ecological balance. In addition to producing more than 50 percent of the oxygen on the planet through the process of photosynthesis, the ocean simultaneously absorbs vast amounts of carbon that helps regulate heat within the atmosphere which, in turn, maintains a sustainable climate. The ocean is home to hundreds of thousands of known species and plants that are harmed from the increased carbon and heat absorption, ocean acidification and anthropogenic waste, particularly in the form of plastics. These actions create a compounding issue that dramatically affects the maintenance of the ocean's ecological balance, thus posing a threat to the marine ecosystem.

This problem is further exacerbated by the fact that the ocean is a major source for human consumption of animal protein which also serves the marine food chain. In addition to a growing global demand for fish and other seafood that has significantly stressed ocean fisheries, the harm caused by plastics and other marine debris, through entrapment, ingestion, starvation and toxic poisoning further imperils the sustainability of this critical ocean resource. Consequently, a principal food source for coastal communities is reduced and their economic welfare is negatively impacted since many coastal populations depend on the ocean for their livelihood.

With the majority of global commerce conveyed to its major distribution hubs via shipping, the growing risk to navigation presented by floating plastics and marine debris such as that found in, but not limited to, the large ocean gyres is compelling. This represents a significant concern when considering the larger economic contribution shipping makes to the global economy.

The voluminous amount of debris that enters the ocean each year, via unrestricted coastal waters and thousands of rivers, has inundated the ocean with plastics. This pollution is not only limited to surface congregation in the large ocean gyres, or garbage patches, but also permeates the entire water column from surface to seafloor making plastics and their sub forms such as microplastics and toxins ubiquitous within the ocean environment. This debris is of growing international concern because it significantly damages the ocean's ecological system, negatively impacts a major food resource, creates hazards to navigation, diminishes marine livelihoods and tourism, and poses a significant risk to the larger global economy. The amalgamation of these stressors is compounded by the uncontrolled entry of plastic debris into the marine environment thus creating an existential threat to the various marine ecosystems and the ocean writ large. If unchecked, this threat might cause the catastrophic collapse of the marine ecosystem, upon which all life on earth is based. The following chapter will investigate means by which we regulate collective issues and provide a foundation for later discussions of ocean and marine debris governance.

CHAPTER III

GOVERNANCE: UNDERSTANDING FUNCTION AND MEASURING EFFECTIVENESS

"People's participation is the essence of good governance."[107]

- Narendra Modi, Prime Minister of India

"Existing government structures, siloed, technocratic and hierarchical, have been incapable of effectively addressing wicked problems, and of meeting the public's expectation that it is government's job to resolve such issues. This apparent lack of capability further erodes public trust, which makes it even harder to address the challenges – and so the governance gap widens."[108]

- Robert Weymouth and Janette Hartz-Karp, Professor Emeritus, Curtin University

Introduction

When a particular species, an ecosystem, a community, a state, or the planet itself is faces an existential threat, particularly those in which the human population is a contributor, it is imperative that governments act to mitigate that threat to preserve the value deemed to be at risk. Governance is the means by which action is designed, implemented and administered to effect a solution, yet there are inherent challenges to governance that often hinder timely and effective action to curtail and even reverse these threats.

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[107] Narendra Modi, "Journey Towards Empowerment with Mygov," Government of India, https://blog.mygov.in/journey-towards-empowerment-with-mygov/.

[108] Robert Weymouth and Janette Hartz-Karp, "Deliberative Collaborative Governance as a Democratic Reform to Resolve Wicked Problems and Improve Trust," *Journal of Economic and Social Policy* 17, no. 1 (2015): 1.

In the case of plastic marine debris, the global commons, which lacks effective governance, faces an ever-increasing existential threat as the marine environment continues to be bombarded by plastic matter that diminishes the ecosystem's function. In order to better understand the governance role throughout the remainder of this dissertation, this chapter offers a conceptualization of governance, by defining and exploring the applications of governance that are pertinent to the marine commons. After an initial review of the historical underpinnings and relevant literature, a practical definition of governance will be presented for application throughout the remainder of this project. This will be followed by a discussion of the multi-level applicability of governance at the sub-national, national and supra-national level as well as a brief look at participatory governance. In each case, examples will be presented to further illustrate the discussion points. A discussion of governance in the global commons, supplemented by several examples, will follow and lead to an examination of measures of effectiveness.

What is Governance?

A word originally derived from the Greek term "kubernaein," meaning "to steer," governance has, in recent years, become a rather prolific term. It has not played such a prominent role throughout history, particularly in its current adaptation. One of the earliest English uses of the word is attributed to Charles Plummer's 19th Century edited translation of Sir John Fortescue's 15th Century Latin work *The Governance of England: Otherwise Called The Difference between an Absolute and a Limited Monarchy.* As the title implies, Fortescue's treatise centers on a debate between royal and parliamentary rule; the first grants a king the rule of his subjects through laws he makes himself and the second denies a king rule of his people by any laws other than those they assent to. In this context, governance concentrates on overseeing the administrative and management of a government's society and daily function. References to governance throughout the succeeding centuries indicate similar understanding of the term where the meaning has long been synonymous with the word government and was primarily used to refer to administrative and political undertakings. While this remains true in the context of a state's national affairs, the term has expanded from that which is noted in historical literature to more recent interpretations beyond a similitude with government.

More recently, governance has evolved and become less synonymous with government - an administrative body of a state or community – and more with a broader society of interests. British scholar Mark Bevir describes it as differing "from government in that it focuses less on the state and its institutions and more on social practices and activities."[109] Understanding governance is to understand process in that it is a technique utilized for guidance and control (or oversight) through which entities focus on procedural application of decision-making, behavior and accountability. It is centered on implementing structure around how an agency designs its strategy to facilitate a path for achievement of a calculated goal(s) for a specific issue area, to include measurements of effectiveness. Through the imposition of rules of behavior, participants collaborate in order to achieve specified goals.

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[109]Mark Bevir, *Governance: A Very Short Introduction* (Oxford: Oxford University Press, 2012), 1.

The World Bank Institute produced one of the early and more commonly cited definitions:

> "The traditions and institutions by which authority in a country is exercised. This includes (1) the process by which governments are selected, monitored and replaced, (2) the capacity of the government to effectively formulate and implement sound policies, and (3) the respect of citizens and the state for the institutions that govern economic and social interactions among them."[110]

Yet, governance is not limited to states, and the challenges associated with the global commons have driven the term to remain loosely defined, deliberately perhaps. It is imperative to note that governance is much more than, and by those terms different from, government because it relies on many actors, of which a respectable percentage have nothing to do with governments. Governance is also about establishing rules and norms, changing expectations, modifying behavior and changing cultures (e.g., plastic consumption) which reveals that governance not only works with multiple actors but also on multiple levels. Perhaps more suitable is David Levi-Faur's definition: "governance is an interdisciplinary research agenda on order and dis-order, efficiency and legitimacy all in the context of the hybridization of modes of control that allow the production of fragmented and multidimensional order *within* the state, *by* the state, *without* the state, and *beyond* the state."[111] Useful ocean governance then "requires globally-agreed international rules and procedures, regional action based on common principles, and national legal frameworks and integrated policies."[112]

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[110] D. Kaufmann, A. Kraay, and Pablo Zoido-Lobatón, "Governance Matters," Policy Research Working Paper (Washington DC: World Bank Institute, 1999), 1.

[111] David Levi-Faur, "From Big Government to Big Governance," in *The Oxford Handbook of Governance*, ed. David Levi-Faur (Oxford: Oxford University Press, 2012), 3.

[112] Pyc Dorota, "Global Ocean Governance," *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation* 10, no. 1 (2016): 159.

Governance is a somewhat amorphous process in that there is no one construct suitable for all purposes; however, there are a few key elements that not only pertain to marine debris but generally apply to all challenges presented in the global commons: multiple and varying levels exist; a particular kind of problem is involved; actor participation is voluntary under most circumstances; support from certain actors may be more important than that of others and collaboration is required between different actors. Critical to any form of regulation or control, sufficient measures of effectiveness are also required to determine success or failure of governance initiatives. In the following sections, an in-depth review of governance and its applications will be conducted while an introduction to measures of effectiveness will be presented. For the purposes of this project, governance will be defined as a process that utilizes rules and norms for guidance and accountability of behavior to effect a desired outcome.

Governance Application at Three Distinct Levels

In order to better comprehend the distinction between the varying levels of governance, a brief review of its use and application in terms of each agency is appropriate. The lens through which these agencies will be viewed is that of three general levels represented by the sub-national, the national and the supra-national.

Sub-national

The sub-national, defined as any active governance below the nation-state, includes various actors, from individuals to a multitude of local community bodies (Community can also be considered in terms of a shared interest on a broader scale which will be addressed later).

Local communities, tribes, cities or provinces tackle governance at a level where the state, or its governing body, often abdicates certain aspects of governance to local and regional entities. While this level of governance is often less emphasized for international relations (IR) scholars, it is increasingly seen as playing a prominent role. Andy Pike and John Tomaney's editorial on this issue assesses the expansion of sub-national governance and further scholarship, while asserting that national configurations "have become less prevalent as nation-states have experimented with - sometimes nominally - more devolved and decentralised institutional arrangements."[113] This is not to imply states' function is declining; instead it highlights the increasing role sub-national entities perform in governance.

These sub-national actors will often govern issues such as water use, regulation of commerce, and the management of formal education structures. In the context of plastic marine debris, sub-national governance at the individual and local community level is reflected through examples such as Melati and Isabel Wijsen, two sisters in Bali, Indonesia who, as teenagers in 2013, started the initiative <u>*Bye Bye Plastic Bags*</u> to address the plastic bag problem in their resident coastal waters. Their tenacity and ingenuity led the government of Bali to institute a ban on single-use plastics including shopping bags, styrofoam and straws. This sub-national governing action was implemented under Gubernatorial Regulation (Pergub) No. 97/2018; the policy is anticipated to create a 70 percent decline in Bali's marine plastics within a year with appropriate oversight measures.

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[113]Andy Pike and John Tomaney, "Subnational Governance and Economic and Social Development," *Environment and Planning A* 36 (2004): 2091.

The implementation of Pergub 97/2018, which took effect in June 2019, is designed to incorporate a variable scale of actors that includes producers, suppliers, distributors, retail outlets and individuals, and to require them to substitute plastics with other materials such as vegetable root-based biodegradable bags. Oversight of the policy includes the imposition of administrative sanctions for non-adherents, with the termination of business permits as a consequence.

This initiative was followed by Jakarta's Gubernatorial Regulation No. 142/2019, due to take effect in June 2020. Similarly, single-use plastic bags are banned in modern department stores, supermarkets and traditional markets and, while the regulation carries punishments for shopping centers found violating the ban that range from written warnings and fines to suspension of permits or closure, it allows shops to provide single-use plastic for foodstuffs not wrapped by any packaging. These sub-national governance initiatives are located within the nation state of Indonesia which, as a reminder, is the second largest producer of ocean plastic due to its lack of effective state governance of waste management. While these initiatives are commendable, they have failed to reach a national level of effort and thus only represent regulatory measures on a small percent of the state's population.

Similarly, the city of San Francisco, California first banned plastic bags in 2007 under the Plastic Bag Reduction Ordinance No. 81-07 which imposed a strict bag provision of "recyclable paper bags, and/or compostable plastic bags, and/or reusable bags" by "stores" and "pharmacies" with violations punished via incremental increases of monetary fines.[114] This ordinance was

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[114] *San Franscico Environment Code - Plastic Bag Reduction Ordinance*, File No. 070085, (3/22/07).

amended in 2012 (No. 33-12) to include “all retail establishments in the City”[115] and to require stores add a “10 cent” charge for checkout bags when customers request a bag. This initiative expanded under California Proposition 67 in 2016 when it became a statewide ban. With the implementation of ordinance No. 294-18, food vendors were authorized to provide straws only upon request with violations also punished via incremental increases of monetary fines. It further prohibited the sale or distribution of:

> (1) any Food Service Ware that is not either Compostable or Recyclable, (2) any Food Service Ware made, in whole or in part, from Polystyrene Foam, (3) any single use stirrers, splash sticks, cocktail sticks, or toothpicks made with plastic, including compostable, bio- or plant- based plastic, or (4) beginning January 1, 2020, any Food Service Ware that is Compostable and not Fluorinated Chemical Free.[116]

Furthermore, on August 20, 2019 the city’s airport, San Francisco International, took these initiatives one step further and under their Zero Waste Concessions Program banned the sale of plastic water bottles on its premises, instead offering the same product in “recyclable and reusable aluminum and glass containers.”[117] California AB1884 expanded the ban on plastic straws in sit-down restaurants across the state. These actions illustrate San Francisco and California’s governance efforts to control plastic waste and its migration into local waters at a

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[115] *San Francisco Environment Code - Checkout Bags; Checkout Bag Charge*.

[116] *San Franscico Environment Code - Single-Use Food Ware Plastics, Toxics, and Litter Reduction*, File No. 181004.

[117] City and County of San Francisco Airport Commission, "SFO - Plastic Free," San Francisco International Airport, https://www.flysfo.com/environment/plastic-free.

sub-national level. Like Bali's and Jakarta's efforts, San Francisco and California's actions account for approximately 12 percent of the US population affected by the bans.[118]

The other mutually understood use of the term community is as an organizing ideal for individuals who share a common interest. In this context, community can be perceived as a value of commitment to or trust in a specific purpose.[119] The term represents a sense of belonging for people; they "construct community symbolically, making it a resource and repository of meaning, and a referent of their identity."[120] A community constructed around ideals and purpose affords its members an exchange of thoughts, concepts, knowledge, and suggestions about the common purpose – people who may otherwise have limited connection with each other outside the community. The behavior of individuals, states or other organizations helps establish the community's boundaries and identity.

A common example of community is religion which stakes its value of commitment to a shared belief or behavior. The common ideal of a higher power unites individuals in a common purpose to practice teachings and spread beliefs understood to represent the intent that constitutes a particular religion. The ethical principles shared by environmentalists has led to another type of expanding community - marine debris advocates.[121] With a strong sense of

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[118] This percentage was determined by data obtained from the United States Census Bureau populations estimates for 2018, https://www.census.gov/quickfacts/fact/table/CA,US/PST045218.

[119] Elizabeth Frazer, *The Problems of Communitarian Politics: Unity and Conflict* (Oxford: Oxford University Press, 1999), 76.

[120] A.P. Cohen, *The Symbolic Construction of Community* (London: Tavistock, 1985), 118.

[121] Dismas A. Masolo, "Community, Identity and the Cultural Space," *Rue Descartes*, no. 36 (2002): 22.

purpose and sufficient organization, this form of community flourishes through social governance as opposed to the more traditional legally-imposed governance. Regardless of the context of community, in terms of governance, it is a sub-national entity.

National

According to the UN, national governance is:

> "…the exercise of economic, political and administrative authority to manage a country's affairs at all levels, and it comprises mechanisms, processes and institutions, through which citizens and groups articulate their interests, exercise their legal rights, meet their obligations and mediate their differences (United Nations Development Programme, 1997b). Specific forms of governance practices vary widely across countries and are shaped by each country's political, social and economic contexts, but good governance in general comprises the rule of law, effective institutions, transparency and accountability in the management of public affairs, respect for human rights, and the participation of all citizens in the decisions that affect their lives. Good governance also requires effective political leadership that promotes strategic vision and broad consensus on policies and procedures that are needed to foster peace, stability and development."[122]

Unlike the sub-national level, the national level has only one actor - the state itself. While there may be branches of the state that aid in governance, the responsibility lies entirely with the state. The state is the principal body or level with which traditional governance applications are associated. States, by virtue of their national sovereignty, possess the inherent right to establish rules and the means by which those rules are directed and enforced within the boundaries of their sovereign territory. State governance is broad-ranging and national actors

[122] United Nations Department for Economic and Social Affairs, "World Economic and Social Survey 2014/2015: Learning from National Policies Supporting MDG Implementation," in *World Economic and Social Survey* (New York, 2015), 142.

will often govern issues such as those associated with the rule of law: the production and consumption of energy; the production and management of money, trade, communications, and immigration; and the raising, training and operation of militaries.

In the context of plastic marine debris, national governance is exhibited by examples such as the 2017 ban on plastic bags in Kenya. In 2018, the United Nations Environment Program (UNEP) reported Kenya's third attempt was more robust because it was supported with penalties of up to $38,000 or a four-year incarceration, reportedly the most severe consequences of any such ban globally, though outcomes are yet to be determined.[123] Another example from the UNEP is Morocco's 2016 ban that resulted in an extreme reduction of plastic bag usage with the aid of robust penalties to enforce the measure.[124] Of note, more than 20 states in Africa have bans on plastic bags and/or Styrofoam though the impact of each state's ban is unclear due to the variation in mechanisms of, and interest in, enforcement. Yet, each state's independent action highlights a fundamental challenge to addressing the plastics problem on a global scale which is the lack of coordination among states regarding implementation and enforcement. This global absence of uniformity hampers scaling the efforts within Africa and beyond.

In October 2015, in an effort to reduce plastic bag use, the United Kingdom (UK) introduced a five pence charge on plastic bags in large retail stores. As of December 2018, many stores across Scotland, Wales and Northern Ireland have implemented the charge. The

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[123] United Nations Environment Programme, "Single-Use Plastics: A Roadmap for Sustainability," (Nairobi: United Nations Environment Programme, 2018).

[124] Ibid., 29.

result - over 15 billion bags were removed from circulation. This initiative also strongly encouraged retailers to donate the proceeds from bag charges, consequently, 249 retailers in England contributed over 51 million British pounds to charities and good causes.[125] The progressive governance of this initiative led to government consultations to increase the charge to ten pence per bag with an application across all retail stores.[126] Furthermore, in January 2018, the UK's Environment Secretary announced a ban on the manufacture of products, containing microbeads, closely followed by a ban on the sale of such products that entered into force in June of the same year.[127] This was followed, in May 2019, with the announcement of a ban on plastic straws, cotton buds (i.e. Q tips) and drink stirrers that would commence in April 2020.[128] These initiatives are supported by a government Resources and Waste Strategy that "seeks to redress the balance in favour of the natural world…[by moving] to a more circular

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[125] Government of the United Kingdom Department for Environment Food & Rural Affairs (DEFRA), "Single-Use Plastic Carrier Bags Charge: Data in England for 2017 to 2018," (London, 2019).

[126] Government of the United Kingdom, "Plastic Carrier Bags: Gove Sets out New Measures to Extend Charge," news release, December 27, 2018, https://www.gov.uk/government/news/plastic-carrier-bags-gove-sets-out-new-measures-to-extend-charge.

[127] More specifically the microbeads ban was designated for England and Scotland according to the GOV.UK. "World Leading Microbeads Ban Comes into Force," news release, June 19, 2018, https://www.gov.uk/government/news/world-leading-microbeads-ban-comes-into-force.

[128] This action was specific to England. "Gove Takes Action to Ban Plastic Straws, Stirrers, and Cotton Buds," news release, 22 May, 2019, https://www.gov.uk/government/news/gove-takes-action-to-ban-plastic-straws-stirrers-and-cotton-buds.

economy which keeps resources in use for longer – [and states the UK] must reduce, reuse and recycle more"[129] to achieve their goals.

Similarly, in December 2015, the US Congress passed H.R. 1321 (Public Law 114-114), the Microbead-Free Waters Act of 2015 which prohibits the manufacturing, packaging, and distribution of microbeads. More specifically, it banned these tiny pieces of plastic that act as exfoliants in face washes, toothpastes, and other personal-care products with legal application to products that are both cosmetics and non-prescription. This legislation was passed to address rising concerns surrounding microbeads in the water supply. Microbeads were intentionally manufactured in facial scrubs and toothpaste to act as a minor abrasive, yet when rinsed off, the plastic beads enter the water system with no assurance that they will be filtered through existing treatment systems. Without such protections, there was an increased risk of the microbeads flowing into the bodies of water where they pose numerous threats including consumption by fish and wildlife.[130]

The actions of Kenya, Morocco, the UK and the US illustrate individual governance efforts to curb portions of plastic waste and to be stewards of the marine environment at the national level. States certainly can institute governance measures and possess the means to enforce those measures. However, when dealing with an issue on a global scale, if only a handful of states take aggressive action on only portions of the problem, *not uniformly or*

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[129] "Our Waste, Our Resources: A Strategy for England," ed. Department of Environment and Rural Affairs (London: Crown, 2018).

[130] US Food and Drug Administration, "The Microbead Free Waters Act: FAQs," US Government, https://www.fda.gov/cosmetics/cosmetics-laws-regulations/microbead-free-waters-act-faqs.

cohesively, it is likely to have little impact on the broader issue if the majority of states demonstrate no governance or ineffective governance on the same issue. Coordination realized at the supra-national level is therefore the third area of governance.

Supra-national

While the activities of state governance are numerous and demanding in the domestic arena, they are equally plentiful and taxing beyond the national level. Governance above or outside the national level can take several forms to include: International Organizations, Intergovernmental Organizations, International Non-Governmental Organizations, International Institutions, and Multinational Corporations. This presents a challenge for governance because confusion may arise regarding terms and roles of governance entities outside/above the national level. Accordingly, a brief review follows to clarify these various labels.

International Organizations (IOs) are bodies or entities that function in the international arena, outside the jurisdiction of a single sovereign state or under a unitary state actor's oversight. They are assemblages of people, communities and/or states who unite to undertake a common goal. As presented by scholars Lisa Martin and Beth Simmons: "International organizations are associations of actors, typically states. IOs have membership criteria and membership may entail privileges (as well as costs.)"[131] Intergovernmental Organizations, Non-Governmental Organizations, and Multinational Corporations are all IOs and beg a brief review for clarity.

[131] Lisa L. Martin and Beth A. Simmons, eds., *International Organizations and Institutions, Handbook of International Relations, 2nd Edition* (Los Angeles: Sage Publications Inc., 2013), 329.

Intergovernmental Organizations (IGOs) are bodies created by a treaty that involve two or more states and are designed to work on issues of common interest in good faith. The formation of such bodies through a treaty affords IGOs the ability to create enforceable agreements and to make them subject to international law. IGO governance is wide-ranging with these actors tasked with overseeing issues from the World Trade Organization's (WTO) regulation of trade between states, to the European Union's (EU) responsibility for the security and flow of trade, labor, and technology among its 27 member countries,[132] to the UN's charter is far-reaching to address problems confronting the international community such as sustainable development, human rights and peace and security.

With the establishment of the International Maritime Organization (IMO) in 1948, formerly designated the Inter-Governmental Maritime Consultative Organization, an agency of the UN was created and accorded responsibility for the safety and security of shipping as well as the prevention of marine and atmospheric pollution by ships. While the founding convention did not include environmental concerns or pollution, after a devastating oil spill in the late 1960s and subsequently rising social interest in the environment, concerns were elevated and amendments ensued, resulting in the present stipulations of Article 1(a) of the Convention, that provides

> "machinery for cooperation among Governments in the field of governmental regulation and practices relating to technical matters of all kinds affecting shipping engaged in international trade; to encourage and facilitate the general adoption of the highest

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[132] The European Union was formerly comprised of 28 members; however, effective January 31, 2020 the United Kingdom formally withdrew from the European body with the implementation of their BREXIT initiative.

practicable standards in matters concerning maritime safety, efficiency of navigation and prevention and control of marine pollution from ships".[133]

As stipulated by the IMO, the role of this IGO is to “create a regulatory framework for the shipping industry that is fair and effective, universally adopted and universally implemented. [In so doing it creates] a level playing-field so that ship operators cannot address their financial issues by simply cutting corners and compromising on safety, security and environmental performance.”[134] These guidelines and taskings highlight ways in which IGOs function in a governance role.

Non-Governmental Organizations (NGOs) are voluntary groups of individuals or organizations that are predominantly nonprofit. NGOs are formed to advocate for a common interest by providing education, analysis, expertise and, at times, on-the-ground assistance while also occasionally helping monitor and implement international agreements. Like IGOs, NGOs cross a broad spectrum of initiatives represented by the likes of Amnesty International’s task of tackling human rights injustices to Médecins Sans Frontière’s mission to “provide medical assistance to people affected by conflict, epidemics, disasters, or exclusion from healthcare,”[135] to planetary/environmental groups like the Club of Rome (The Club).

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[133] International Maritime Organization, "Convention on the International Maritime Organization," (Geneva: United Nations, 1948). This wording comes from the 1975 and 1977 London amendments which can also be located at https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XII-1-d&chapter=12&clang=_en.

[134] International Maritime Organization, "Introduction to the IMO," United Nations, http://www.imo.org/en/About/Pages/Default.aspx.

[135] Médecins Sans Frontières, "About MSF: An International, Independent Medical Humanitarian Organisation," Médecins Sans Frontières, https://www.msf.org.

The Club is a membership organization think tank of scientists, economists, business leaders and former prominent politicians pursuing solutions to complex global issues. It provides governance, and advocacy for governance, through research, policy proposals and top-tier conferences and meetings. The Club focuses on the human impact on the earth's systems, predominantly as a result of the past century's exponential population growth and consumption.[136] As early as the 1980s, The Club commissioned a report on the future of the oceans by the eminent environmental activist and ocean scholar, Elisabeth Mann Borgese. This report raised several concerns about the increasing harmful impact of the laissez-faire approach to an ocean economic system in ungoverned ocean spaces, and advocated for multinational integrated management aspiring to break through national boundaries.[137] These examples demonstrate a few of the governance functions NGOs perform and while NGOs can be organized on multiple levels, their role at the international level places them in the context of an IO.

Multinational Corporations (MNCs) are companies that have established assets such as administrative offices, factories or distribution facilities in at least one state other than the state in which they are based. The latter is often its state of origin and is where coordination of their global operations and management occurs. MNCs often have exceedingly large budgets (far larger than some states') and can represent a single product or a variety such as Coca Cola's

[136] A more complete explanation of the Club of Rome can be found on their website page "About the Club of Rome," https://clubofrome.org/about-us/.

[137] Elizabeth Mann Borgese, "The Future of the Oceans: A Report to the Club of Rome," (1986).

vast beverage domain, Google's global technology reach, and Proctor and Gamble's global provision of personal and home care products.

Governance influences how a MNC's objectives are set and achieved, how risk is monitored and addressed, and how performance is optimized. When pondering plastic marine debris, corporate governance leads one to assume that the producer's objective is to generate significant product volume, with minimum cost and maximum profit, thus generating enormous amounts of plastic without necessarily placing as much concern on what happens to the product in the long-term. The goal is low-cost output that generates financial profit. Existing corporate governance literature focuses almost entirely on the microcosm of the corporate arena, yet MNC's play a far greater role in governance. Given their vast reach and their global economic impact (which accounts for a significant volume of employment in many otherwise economically-challenged states), MNCs harness a substantial amount of global power, actively govern through their position of influence, and thus hold a prominent role as an IO.

While frequently used interchangeably with IOs, not all International Institutions (IIs) are IOs. Scholars have clarified the term in various ways, one of which is Martin and Simmons' seminal work on IIs that reviews definitions by the likes of Elinor Ostrom and John Mearsheimer and determines that IIs are not actors but "sets of rules meant to govern international behavior."[138] The governance of these rules can have far reaching impact, thus making institutions an essential component of international, as well as local, governance efforts to

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[138] Martin and Simmons, 2013, 328.

structure political, social and economic interaction.[139] Ostrom argues the importance of institutions in *Governing the Commons* with the assertion that "communities of individuals have relied on institutions resembling neither the state nor the market to govern some resource systems with reasonable degrees of success over long periods of time."[140]

Meanwhile, John Duffield's similar canvas of scholarly definitions produced a more detailed understanding of IIs, asserting they are "relatively stable sets of related constitutive, regulative, and procedural norms and rules that pertain to the international system."[141] To further clarify the term "rules," it refers to "statements that forbid, require, or permit particular kinds of actions."[142] As such, some IOs can be IIs though not all IIs are IOs. Students of IR may confuse these II definitions with what is also understood to be a "regime," a term which has comparable definitional literature in works by notable IR scholars such as Stephen Krasner and Robert Keohane.[143] In response, it should be pointed out that scholarship concludes that the term "institution" has essentially supplanted the long-used IR term "regime."

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[139] Elinor Ostrom asserted that "institutions affect the performance of economic and political systems'" in her seminal work *Governing the Commons: The Evolution of Institutions for Collective Action*, New York: Cambridge University Press, 1990, see xi. I take this a step further to include social systems since social behavior is strongly influenced by institutions.

[140]Ostrom, *Governing the Commons : The Evolution of Institutions for Collective Action*, 1.

[141] John Duffield, "What Are International Institutions?," *International Studies Review* 9, no. 1 (2007): 2.

[142] Martin and Simmons, *International Organizations and Institutions, Handbook of International Relations, 2nd Edition*, 328. This definition is derived from Ostrom's work in *Governing the Commons.*

[143] Several works in the 1980s through the early 2000s focused on the predominant IR term "regime." Notable works in this area are Stephen D. Krasner, *International Regimes* (Ithaca: Cornell University Press, 1983). and Robert O. Keohane, *After Hegemony: Cooperation and Discord in the World Political Economy* (Princeton: Princeton University Press, 1984).

Examples of institutions include the ageless art of diplomacy. This skillful interaction of people, most notable in the IR arena, is recognizable by the sensitive and respectful rules and norms that govern often delicate proceedings between parties. Keohane asserts that international institutions (regimes) perform a central role in explaining the behavior of states in the international system. Diplomacy is a regulation of behavior both of the individual or group conducting the diplomacy and the entity represented.[144] A second example, and one of the most prominent, of an international institution has long been the Nuclear Non-Proliferation Regime which grew out of the development and spread of nuclear weapons technology following the Second World War. The objective of this institution is to amalgamate international agreements, organizations and domestic legislations to inhibit the spread of nuclear weapons, consolidating intentions and efforts for a common purpose. Finally, the IPCC, a subset of the UN and thus an IO, is tasked with addressing one of the most pressing global issues and is thus a prominent actor of institutional influence. All three examples are not only comprised of state actors but of multi-level experts, indeed "influencers," at the supra-national level.

Since institutions facilitate cooperation among actors and regulate behavior associated with a particular issue based on an assemblage of principles, rules and norms, it is not a large step to take in order to reach the determination that there is greater similarity between institutions and governance than between institutions and organizations. This is significant because governance is often considered in the context of a governing body like an organization,

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[144] *After Hegemony: Cooperation and Discord in the World Political Economy*, 57.

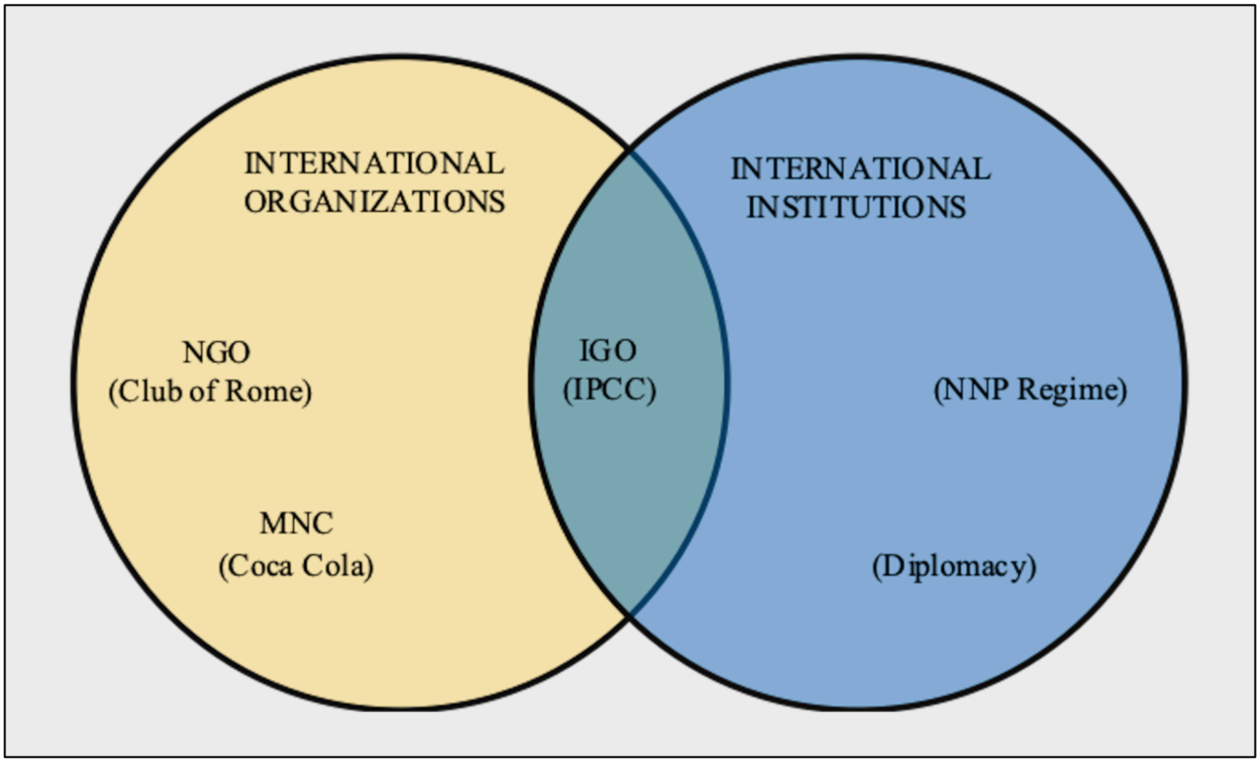
however, the establishment of principles and norms that regulate behavior is perhaps more important in effecting successful governance than rules implemented by organizations without a moral or normative foundation to ensure compliance. Nevertheless, IIs and IOs both perform critical functions of governance with applications across a spectrum of issues to include marine debris.

If the application and understanding of these terms seems complex, it is because the way in which the international arena functions is extremely complicated, which makes governance challenging at the supra-national level. The multitude of actors and international governing bodies in which they may participate are vaster and more varied than that described above, yet this short overview is an attempt to provide a glimpse into the intricacies of international governance challenges. Not only is understanding the purpose and function of the broadest categories of international governance difficult, the multi-tiered compartmentalization of these bodies is also confusing. Compound this with problems that lack a simple solution, cross sovereign boundaries, multiply at a rapid pace, and involve actors that are primarily focused on their own self-interest highlights how difficult it is to formulate and implement regulatory actions that will engender compliance.

A simple diagram (Figure 3.1) is provided to illustrate the preceding narrative where items in parenthesis indicate examples of each larger entity. The fact that IGOs can be both IOs and IIs is depicted in the intersecting portion of the diagram where the IPCC is both an IO and II.

Figure 3.1

International Organizations and Institutions



One way to think of this is as a system of systems, a concept often associated with engineering, because its broad applications includes communications, electronics, design, governance, and the environment. A system of systems, therefore, is an assembly of multiple, independent systems that together form a larger, more complex system. Governance at the supra-national level is composed of such systems. The challenges of working with such complex systems, particularly in the global commons, will be discussed in further detail in the following chapters.

Participatory Governance

One additional form of governance deserves mention because while regulations are most often imposed in a downward fashion from a higher authority, they can be initiated in the reverse, from the bottom up, as noted in the discussion on communities and the sub-national level. Participatory governance concentrates on strengthening engagement by involving citizens in the processes within its various levels. Per Gustafson and Nils Hertting capture the fundamental notions on this topic and cite the relevant scholarship for each:

> "Proponents of participatory governance expect a range of different benefits from participation, including increased political interest, knowledge and empowerment among individual citizens (Pateman, 2012; Rogers & Weber, 2010; Talpin, 2011), increased inclusion of affected and marginalized participants, interests and discourses (Dryzek & Niemeyer, 2008; Fischer, 2006), better responsiveness on the part of politicians and administrators, and greater collective capacity and expertise to act on complex policy problems (Ansell & Gash, 2008; Danielsson & Hertting, 2007; Sørensen & Torfing, 2007)."[145]

Increasing the political interest, knowledge and empowerment of individual citizens combined with improved responsiveness of politicians and administrators creates a more cohesive effort to address issues in governance. This implies citizens should take more active and prominent roles in public decision-making, perhaps initiating norms and regulatory measures equating to the sub-national, national or even supra-national level that is community with a common purpose. This can be done on an individual basis as represented by the Wijsen sisters in Bali, a cultural basis such as the UK where there is a strong relationship with the ocean

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[145] Per Gustafson and Nils Hertting, "Understanding Participatory Governance: An Analysis of Participants' Motives for Participation," *The American Review of Public Administration* 47, no. 5 (2017): 539.

and citizen attentiveness to environmental management appears to be a growing, or at the supra-national level where NGOs like The Club are composed of like-minded environmental advocates from a multitude of backgrounds and nationalities working with IOs. An additional prominent example of direct citizen involvement in multi-level enterprises is associated with climate change. While the IPCC leads the supra-national efforts to combat climate change, numerous citizen-led initiatives engaging with communities and states are in progress, ultimately attempting to connect all levels to combat this existential threat in the global commons. Regardless of the governance level, when citizens engage with formal governance structures to address a particular problem-set, they often help push the initiatives both outward and upward thus creating a bottom-up governance effect as they seek to solutions to complex issues.

Global Commons Governance Initiatives

In order to help frame governance of marine plastics and the broader marine debris, which is impacted by all levels of governance, but most commonly associated with supra-national, it is useful to review several existing initiatives that address similarly large-scale global commons problems. The first is the 1972 "Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter," otherwise known as the "London Convention." This is one of the first global regulatory initiatives conceived and implemented to safeguard the marine environment from human actions and detrimental impacts. More specifically it seeks to restrict all origins of marine pollution and to avert pollution of the ocean by the disposal at sea of wastes. Originated by the UN's Conference on the Human Environment, this IO governance action sought to achieve a global agreement to cease all marine dumping and ban it in the future. Entered into force in 1975, it was enhanced in 1996 with what has become known as the "London Protocol" which added precautionary and preventive measures that expanded from waste dumping at sea to include land-generated wastes. The London Protocol which entered into force in March 2006, replacing the London Convention of 1972, effectively prohibited all marine dumping.[146]

To increase their effectiveness, international treaties of global application are often reinforced by national level regulatory measures. While not necessary, it adds a layer of certainty of commitment to what is perceived to be more enforceable action at the sovereign state level. In the case of the US, the London Convention was strengthened by national efforts to protect the marine environment with the 1972 Marine Protection, Research and Sanctuaries Act (MPRSA), also known as the Ocean Dumping Act, which implements the requirements of the London Convention for waters under US jurisdiction.[147] The US Coast Guard is charged with surveillance and enforcement of ocean dumping.

The second example is the “United Nations Convention on the Law of the Sea,” otherwise known as UNCLOS. Perhaps the most recognized and continually evolving regulatory effort of the marine commons, UNCLOS originated from centuries-old contentions about sovereignty over territorial seas, measured in nautical miles (NM). Three international

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[146] International Maritime Organization, "Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter," United Nations, http://www.imo.org/en/OurWork/Environment/LCLP/Pages/default.aspx.

[147] United States Environmental Protection Agency, "Ocean Dumping: International Treaties," https://www.epa.gov/ocean-dumping/ocean-dumping-international-treaties.

conventions ensued. The first Geneva Convention, held in 1956, led to four treaties which entered into force in 1964: 1) "Territorial Sea and the Contiguous Zone" addressed territorial partitions of the seas and sovereignty disputes among states, 2) "High Seas" dealt with nuclear tests on the high seas and subsequent pollution by radioactive materials, 3) "Fishing and Conservation of the Living Resources of the High Seas" centered on the conservation of international fisheries and collaboration in conservation efforts; and 4) the "Continental Shelf" attended to resolutions with respect to coastal fisheries and historic waters.

In 1960, a second Geneva Convention was convened but did not achieve an international agreement on contentious fishing rights. The third conference ran from 1973 to 1982 and included difficult debates on refinements of the previous treaties, as well as newer topics such as the seabed, provisos for the passage of ships, protection of the marine environment, and freedom of scientific research. It entered into force in 1994. Regardless of the number of treaties or refinements to those treaties, the Convention's overarching task was to emphasize "the fundamental obligation of all States to protect and preserve the marine environment."[148]

From a national level of governance, the US has declined to sign the treaty for reasons most associated with seabed exploration and mining; however, President Ronald Reagan's 1983 "Statement on United States Oceans Policy" acknowledges that UNCLOS "contains provisions with respect to traditional uses of the oceans which generally confirm existing maritime law

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[148] United Nations Division for Ocean Affairs and the Law of the Sea, "The United Nations Convention on the Law of the Sea: A Historical Perspective," https://www.un.org/Depts/los/convention_agreements/convention_historical_perspective.htm.

and practice and fairly balance the interests of all states."[149] The statement is buoyed by the "National Security Decision Directive 83" which confirms that the US would "accept and act in accordance with the balance of interests reflected in the Law of the Sea Convention,"[150] thereby viewing UNCLOS as adhering to the customs and norms of international law.

The final example of global initiatives is The Montreal Protocol on Substances that Deplete the Ozone Layer otherwise known as the "Montreal Protocol," a result of the 1985 Vienna Convention for the Protection of the Ozone Layer created by the UNEP. This international agreement was crafted to safeguard the ozone layer by regulating chlorofluorocarbons (CFCs), through a phase-out process, "the production and consumption of nearly 100 man-made chemicals referred to as ozone depleting substances (ODS). When released to the atmosphere, those chemicals damage the stratospheric ozone layer, Earth's protective shield that protects humans and the environment from harmful levels of ultraviolet radiation from the sun."[151] If left unchecked, the ultraviolet radiation would significantly increase global warming and adversely affect agricultural production due to drought. It is also associated with increased incidences of skin cancer and disrupts marine ecosystems.[152]

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[149] Ronald Reagan, "Statement on United States Oceans Policy," (Washington D.C.: US Government, 1983). This statement was made on March 10, 1983.

[150] "United States Oceans Policy, Law of the Sea and Exclusive Economic Zone (C)," National Security Decision Directive No. 83 (Washington D.C.: US Government, 1983).

[151] United Nations Environment Programme, "About Montreal Protocol," United Nations Environment Programme, https://www.unenvironment.org/ozonaction/who-we-are/about-montreal-protocol.

[152] Office of Environmental Quality and Transboundary Issues United States Department of State, "The Montreal Protocol on Substances That Deplete the Ozone Layer," US Government, https://www.state.gov/key-topics-office-of-environmental-quality-and-transboundary-issues/the-montreal-protocol-on-substances-that-deplete-the-ozone-layer/.

The “Montreal Protocol” was formally adopted in 1987 and went into effect in 1989. In this instance, US national level governance of this global regulatory initiative was reflected positively with ratification in 1988. In 1990, the US Congress amended the Clean Air Act of 1963 with provisions for guarding the ozone layer that included the addition of approximately a dozen regulatory programs.[153]

These initiatives further demonstrate the complexity of governance in the global commons. The scientific data collection and dissemination, information gathering and issue education, and ultimately state bargaining involved in such procedures is often lengthy and requires significant negotiations to forge a compelling course of action. Some of these initiatives initially appear to be quite comprehensive but are later expanded to include subsets not previously detailed in the original provisions. They also often require redundant governance measures at a lower level to assure more enforcement gravitas. The following section addresses the necessity of creating benchmarks to evaluate success or failure.

Measuring Success or Failure

Regardless of the level of governance (sub-national, national, or supra-national), efforts undertaken to effect it are rarely if ever straightforward or without difficulty. The phrase “good governance” has emerged in the past 30 years and loosely implies a benchmark for successful governance, but it is vague and primarily focused on issues related to developing countries. It is

[153] United States Environmental Protection Agency, "Ozone Protection under Title VI of the Clean Air Act," US Government, https://www.epa.gov/ozone-layer-protection/ozone-protection-under-title-vi-clean-air-act.

by no means an all-encompassing or accurate phrase for measuring effectiveness for a given category of governance. This is because the issue at hand, governance of marine plastics, is of significant enough value to require action that inherently has more than one viable course, often is characterized by many obstacles, and has at least an insufficient structure to determine achievement of governance objectives. Therefore, instituting rules and norms that dictate governance of an issue necessitates the establishment of measures of effectiveness to help gauge the usefulness of a particular form of governance.

To determine what markers are useful, two basic questions should be asked. First, what is the objective of a particular governance initiative? In the case of marine plastics, it is to reduce the volume to the maximum extent possible. Second, what factors will be useful to achieve that objective?[154] For this dissertation, variables selected include consumption, recycling, and waste, which will be presented in the following chapter.

Michael Mauboussin's "The True Measures of Success" in the *Harvard Business Review* (2012) provides guidelines for measuring business success and, although the business sector has notable differences, several of his guidelines are useful when attempting to measure sub-national, national and supra-national governance success. The first is to "Define your governing objective,"[155] to which he stipulates such an action is essential. While his business application is centers on capital, in terms of governance, it is crucial to measure the right value or variable and to ensure the value of measurement is understood. In the case of plastics, the value might

[154] Michael Mauboussin, "The True Measures of Success," *Harvard Business Review* 90, no. 10 (2012): 50.

[155] Ibid., 54.

be the volume in the marine ecosystem, the volume entering the ocean from rivers each year or the volume that is removed from coastal cleanup projects each year. The intention is to clarify the objective as much as possible in order to focus governance and remove ambiguity.

The next pertinent guideline is to "Develop a theory of cause and effect to assess presumed drivers of value."[156] Whether the intent is to apply measures of effectiveness to financial gains or to marine health, the demonstration of a causal relationship between an action and the outcome of measurement is imperative. This is due to the predictive nature inherent in a causal relationship between an action and the outcome that is measured. To acknowledge the criticality of this step, a system dynamic model is presented in the following chapter to demonstrate the cause and effect relationship of several key variables contributing to the challenges of governing the marine plastics problem.

The last of Mauboussin's guidelines germane to governance measures is to "Regularly reevaluate the chosen statistics to ensure that they continue to link… activities with the governing objective."[157] This is applicable across governance topics since over a given period of time diverse matters will influence the value of measurement: Political leanings, economic drivers, emerging pandemics or myriad other influencing agents, randomly cause changes. So, it is necessary to reassess the framework of measurement as well as the measurements themselves on a recurring basis.

It is essential for a company, community, state, organization or institution to achieve its objectives and drive improvement, as well as maintain legal and ethical standing in the eyes of

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[156] Ibid.

[157] Ibid., 56.

shareholders, regulators and the wider community. In the event the objectives are not achieved, or if the legal and/or ethical standings are not respected, the governing body's reputation is at risk. While legal enforcement of norms and regulatory measures in the global commons is difficult, reputational costs play a significant role in how actors participate and are held to account. Martin and Simmons highlight this point: "Most empirical studies in the rational functionalist tradition, however, argue that IOs and IIs raise costs for noncompliance not through organized punishment as much as through "reputational" consequences. "Reputation" was, of course, one of the main mechanisms Keohane developed in his original functional theory of regimes. Several empirical studies rely on reputational costs to account for their findings."[158]

In the context of marine debris, Mauboussin's measures can be used to evaluate decreased plastic consumption and overall production, increased recycling and waste management (plastic specific), and implementation of enforceable regulations applicable across the spectrum since all types of plastic end up in the ocean in one form or another. While this may seem daunting, precedent does exist for the success of large-scale global commons measurement in previous examples which can be further explored.

Maritime specific, the London Convention and Protocol prohibits all marine dumping, with few exceptions, to include industrial wastes (including munitions), material produced for biological and chemical warfare, and the incineration at sea of industrial waste and sewage sludge. It also provides a platform for consultation on a wide range of issues that impact the

[158] Martin and Simmons, *International Organizations and Institutions, Handbook of International Relations, 2nd Edition*, 337.

marine environment. Similarly, UNCLOS has formerly established territorial lines of sovereignty, many of which had long been accepted through customary practices, with the key examples being the Territorial Seas (12 NM), the Contiguous Zone (32 NM) and the Exclusive Economic Zone (200NM). It also establishes that any sea area not part of a sovereign state (to include the previously defined waters) as the “High Seas” which are for peaceful purposes and allows for the freedoms of navigation, overflight, fishing, and scientific research.[159] While neither of these agreements have specific database measures that adhere to a common standard across states, they have both instituted an ocean governance structure of rules and practices through a normative approach that is underscored by adverse reputational costs, should actors at all levels not comply.

Meanwhile, stratosphere-focused but marine-applicable, the Montreal Protocol “is to date the only UN environmental agreement to be ratified by every country in the world and considered by many as the most successful environmental global action.”[160] It is also one of the most successful as demonstrated by “the parties to the Protocol having phased out 98 per cent of their ozone-depleting substances.”[161] Furthermore, the UN estimates that millions of people have been spared from skin cancer as a result of this governance action and that with “the full

[159] For additional information, please refer to the London Convention and Protocol as well as the United Nations Convention on the Law of the Sea.

[160] United States Environmental Protection Agency, "International Actions - the Montreal Protocol on Substances That Deplete the Ozone Layer," https://www.epa.gov/ozone-layer-protection/international-actions-montreal-protocol-substances-deplete-ozone-layer.

[161] United Nations Environment Programme, "Thirty Years on, What Is the Montreal Protocol Doing to Protect the Ozone?," United Nations Environment Programme, https://www.unenvironment.org/news-and-stories/story/thirty-years-what-montreal-protocol-doing-protect-ozone.

and sustained implementation of the Montreal Protocol, the ozone layer is projected to recover by the middle of this century."[162] Yet without it, the UNEP asserts that by 2050 ozone depletion would have increased tenfold. One additional measure of success is the scientific evidence that combined both statistical analysis of the hole in the ozone and its chemical composition to confirm the hole is decreasing and is due to the decline in chlorofluorocarbons.[163]

Each of these supra-national initiatives has generated robust discussions in an organized format, discussions facilitated by an urgency associated with a particular problem. The London Convention and Protocol was driven by waste that posed an increasing threat to sanitation, transport and livelihoods while UNCLOS was prompted by increasing challenges to sovereignty while the demand on stressed resources required states to seek greater alternatives outside their customarily acknowledged boundaries. The Montreal Protocol was a result of the recognition of a shocking and existential threat to one of life on earth's greatest protective barriers. Each has brought states and experts from a variety of backgrounds together to address numerous challenges of common interest that affect the broader global population in one way or another. Ultimately, a sufficient number of participating states have ratified these conventions, and many of those states have implemented their own national level governance measures thus underscoring the rules and norms analogous to the broader governance effort that have imposed behavior modification, increased awareness and social

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[162] "About Montreal Protocol".

[163] Susan E. Strahan and Anne R. Douglass, "Decline in Antarctic Ozone Depletion and Lower Stratospheric Chlorine Determined from Aura Microwave Limb Sounder Observations," *Geophysical Research Letters* 45, no. 1 (2018).

responsibility. This highlights that maintaining an intact reputation is perhaps the most dominant measure of success.

Failure, ostensibly the opposite of success, is no more clear-cut and trouble-free in the sense of establishing tangible parameters. Broadly, failure can be understood as a lack of change in behaviors thus producing less than desired outcomes. In the context of marine debris, it can be measured on several levels to include continued current levels or increases in plastic consumption and overall production, decreased recycling and waste management (plastic specific) and either the lack of implementation of enforceable plastics regulations or the failure to actually enforce existing regulations that all harken back to the cautions of Hardin's "Tragedy of the Commons."

The preceding portion of this section highlighted successes of three specific governance actions, yet each of those could also be argued as failures in some capacity. Perhaps the most tenable argument across the three is that there is no universally agreed upon means by which the actions of all actors can be captured as relates to each treaty or agreement. This is an underlying problem in a world where the idea of global governance is hotly contested with little to no progress, thereby ensuring no recognized global enforcement mechanism is acknowledged and galvanized.

Returning to previous cases in this chapter, weaknesses in state participation in and commitment to international agreements provide relevant examples for governance failures. First, the London Convention was initially negotiated more than 40 years ago, yet it has only 87 states signed on as parties. Meanwhile, the London Protocol, negotiated more than 20 years ago to update and implement more robust measures that would significantly improve the marine environment in regard to dumping and waste issues has even fewer parties with only 53. As with most agreements, the issue area is broad and while anti-dumping seems straightforward, it has proven difficult to clarify and led to the 1996 London Protocol's replacement of the original convention. However, there remains one primary challenge associated with carbon capture and storage in Article 6 which prohibits exports of wastes for dumping in the marine environment: It hampers states' practice of transboundary export of CO^2 for sub-seabed geological storage. The end result is that only a small number of states have become party to the London Protocol and as such, the remainder are not compelled to be held to the same standards regarding ocean dumping, resulting in a helpful, but ultimately weak, agreement for the protection of the marine environment.

Similarly, UNCLOS enshrined long-held customary practices with regard to marine territorial claims, yet not all countries recognize or adhere to those regulations. This is exemplified by the territorial disputes in the South China Seas, most notably between China, the Philippines, Vietnam, Indonesia, and Brunei. As previously mentioned, the US has declined to sign the convention, but the most disconcerting issue associated with this regulatory effort is perhaps the continuing, and arguably growing, cases of non-compliance by those who have signed it. While the majority of states are party to UNCLOS, "at least one-third…(and quite possibly more) are in breach of at least one significant provision of the LOSC [Law of the Sea Convention]." [164] Party signature can be considered a measurement of success, yet signature

[164] Robin Churchill, "The Persisting Problem of Non-Compliance with the Law of the Sea Convention: Disorder in the Oceans," *The International Journal of Marine and Coastal Law* 27, no. 4 (2012)., 815.

alone does not guarantee commitment and therefore a change in behavior. In such a case where a state has signed a commitment, via treaty or other formal agreement, yet their actions do not change, the governance initiative is considered a failure because it was unsuccessful in changing the state's behavior. This degree of non-compliance is so significant, that it not only challenges the legitimacy of the agreement, but also destabilizes UNCLOS and affects the ability to enforce associated ocean policies. This threatens the process necessary to sustain ecosystem structure and functions that define global ocean governance.

Considering some of the sub-national and national level initiatives previously mentioned, it is not only worthwhile to recognize the US has not become party to UNCLOS it has also withdrawn from the IPCC's 2015 Paris Agreement demonstrating behaviors that preference a tendency for states to be more interested in their short-term gains than their long-term security. The US has more than ten laws that pertain to the protection of its coastal waters and the ocean, yet it remains in the top 20 countries when ranked by the mass of mismanaged plastic waste, which often ends up in the oceans. [165] This further exemplifies how special interests can drive national action regardless of the implementation of regulatory measures, and how fragmented approaches to governance "fail to address the complex interconnections of marine ecosystems and human activities"[166]

[165] Jambeck et al., "Plastic Waste Inputs from Land into the Ocean," 769.

[166] Klaus Töpfer et al., "Charting Pragmatic Courses for Global Ocean Governance," *Marine Policy* 49, no. C (2014)., 86.

Conclusion

Governance is centrally concerned with the establishment of rules and norms, behavior modification, and management of expectations. This occurs at multiple levels ranging from sub-national entities that include individuals, local communities, tribes, cities or provinces, to the national level where the state is the primary actor, to the supra-national level where international organizations and institutions play a fundamental role. Communities made up of like-minded individuals, groups and organizations exercise their social responsibility to effect change.

How we understand success and failure of the imposition of rules and norms matters because governance attempts would not be useful otherwise. The object of measure must be defined as each example demonstrated, the causal relationship requires exploration to understand how the problem is influenced, and reevaluation necessary after the implementation of new rules or the establishment of new norms to determine their impact the rules and norms reveal. This process will be addressed further in the next chapter through the development of a marine debris specific model. This chapter demonstrates that in an increasingly globalized and complex world, ideal governance strives to play a central role but is challenged by the foundations of government under state sovereignty. This state self-interest leads to less than optimum regulatory efforts at every level of governance, but most notably at the supra-national level where tackling complex problems of the commons requires fervent commitment.

While states' rights remain important, the rules and norms of governance increasingly focus on a broader society of interests as evidenced by challenges society faces in a constantly changing environment. Supra-national bodies have repeatedly attempted to institute rules and norms to tackle global issues, but with marginal success, in large part due to states' self-interest that overrides full compliance. While there is a reputational cost associated with noncompliance, most states have not suffered significantly enough to be brought back into compliance. Meanwhile, individuals are increasingly involved in and responsive to community interests which contributes to the broadening of what was once the exclusive domain of the state. Governance has become a shared space that includes multiple actors and stakeholders at multiple levels.

With the rapid and seemingly unending growth and pervasive nature of marine debris, in the earth's largest global common, obstacles to rectifying the issue or even stemming the flow through current governance approaches suggest further consideration is necessary in order to more accurately comprehend the problem. The following chapter proposes an atypical approach, and reframes marine debris as a wicked problem, supported by a model that aims to illustrate a fundamentally different way to envisage governance.

CHAPTER IV

THE WICKED PROBLEM OF MARINE DEBRIS: A SYSTEM DYNAMICS APPROACH

"…sociological theorizing involves explaining how multiple factors interact in complex, often non-linear, ways to effect social behaviors and in explaining the dynamics by which social agents, groups, teams, organizations, societies, cultures evolve and co-evolve."[167]

- Kathleen M. Carley, PhD., Director of the Center for Computational Analysis of Social and Organizational Systems, Carnegie Mellon University

Introduction

Critical global environmental issues continue to be addressed at the annual meetings of the UN Conference on Climate Change: Conference of the Parties (COP). Despite their best efforts, this gathering of more than 150 Heads of State has realized only nominal enforceable governance outcomes as they struggle to limit global warming and reduce the harmful impact of human activity on the planet.

Like climate change, marine debris and its principal protagonist plastic is an increasing environmental concern with a global reach. It is extremely complex due to the multifaceted aspects of this social-ecological system (SES) and, while complexity theory and SES theory are worthy approaches through which to view marine plastics, this chapter argues that the theory of Wicked Problems is more appropriate due to its explanatory nature. Certain problems that face the global community today appear to be most aptly suited for the wicked problem

[167] Kathleen M. Carley, "Computational Approaches to Sociological Theorizing," in *Handbook of Sociological Theory*, ed. J. Turner (New York: Kluwer Academic/Plenum Publishers, 2001), 1.

framework and this chapter proposes one such case is that of marine debris. It further asserts that, using a systems dynamics approach, a causal loop diagram provides a conceptual tool that facilitates a stock and flow simulation, which can account for the "wickedness" of plastic marine debris.

The ocean covers more than 70 percent of the earth and is a major source of the global ecological balance: it provides oxygen, temperature regulation, transportation, food and economic opportunity, yet it is largely unregulated and exceedingly difficult to manage. As such, the ocean is seen as a global space (in terms of the greater ocean footprint outside national exclusive economic zones) that, without coherent management, contributes to the growing, complicated and wicked problem of marine debris.

Wicked Problems

The field of study that is wicked problems is not routinely associated with international relations (IR) but is most commonly associated with urban planning. Yet wicked problems boast a growing body of literature and, arguably, is well-suited to IR due to its complexity and global applicability. German urban planner and design theorist Horst Rittel introduced the concept of a "wicked problem" 40 years ago, describing it as a social system problem that interacts with other systems, such as financial and ecological, which is characterized by great uncertainty. Moreover, a wicked problem is a problem that has numerous causes, is exceedingly hard to describe, and does not have a correct solution.[168]

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[168] John Camillus, "Strategy as a Wicked Problem," *Harvard Business Review* 86, no. 5 (2008): 100.

Rittel and fellow planner Melvin M. Webber further clarify the term wicked as meaning " 'malignant' (in contrast to 'benign') or 'vicious' (like a circle) or 'tricky' (like a leprechaun) or 'aggressive' (like a lion, in contrast to the docility of a lamb)."[169] Wicked problems have "many clients and decision makers with conflicting values, and … the ramifications in the whole system are thoroughly confusing."[170] They are "societal problems…(and) are inherently wicked."[171] By definition, they are problematic to solve because they are not only difficult to describe in concrete terms but they also continue to evolve and are, therefore, exceptionally complex.[172]

Marine debris is a problem created by social interaction with the marine environment and, in order to address it, strategists must devise a multi-tiered approach to manage it across communities, companies, governments, and international organizations. Rittel and Webber provide ten characteristics that are associated with wicked problems. These characteristics are designed as a tool to help assess the feasibility of categorizing an issue as a wicked problem rather than establishing a rigid formula and will be addressed in the following pages and applied to their applicability to the topic of marine debris.

The first characteristic of wicked problems is that they do not have a definitive formulation because the "information needed to understand the problem depends upon one's

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[169] Horst W. J. Rittel and Melvin M. Webber, "Dilemmas in a General Theory of Planning," 1973, 160.

[170] C. West Churchman, "Wicked Problems," *Management Science* 14, no. 4 (1967): B141.

[171] Rittel and Webber, "Dilemmas in a General Theory of Planning," 160.

[172] Timon McPhearson, "Wicked Problems, Social-Ecological Systems, and the Utility of Systems Thinking," https://www.thenatureofcities.com/2013/01/20/wicked-problems-social-ecological-systems-and-the-utility-of-systems-thinking/.

idea for solving it."[173] Second, the problems lack an inherent logic that indicates when they have been solved or, as Rittel and Webber state, "wicked problems have no stopping rule."[174]

Similarly, a third characteristic is that solutions for these problems are not "true or false" but instead are "bad or good" or even "better or worse" since both the problem and solution depend upon the point of view of the stakeholders involved. Consequently, the solution then tends to be based on differing judgments and perceptions. Fourth, solutions to wicked problems will create consequences over an expanded period of time and space. Because there is no way to track every consequence, no definitive test exists for a solution to a wicked problem.[175]

Each of these four characteristics applies when considering the planning required to reduce the use of one form of marine debris - plastic. Plastic is a tremendously diverse product used in almost every domestic and commercial environment. It also provides an inexpensive alternative to wood, glass, metal and other such materials, making it economically appealing to most commercial enterprises. In the wealthier global North, many of those enterprises and communities can afford to use significantly less plastic while still maintaining a comfortable economic position. This is not necessarily the case for many communities, companies and businesses of the economically challenged global South that depend on inexpensive plastic, or even plastic scavenged from refuse piles, as their only means for water catchment, packaging and storage containers, and building supplies. This dependence exemplifies the wicked

[173] Rittel and Webber, "Dilemmas in a General Theory of Planning," 161.

[174] Ibid., 162.

[175] Ibid., 163.

problem solution conundrum: reducing plastic production appears to be a significant step forward in tackling the marine debris problem; however, it simultaneously exacerbates the situation already facing impoverished areas whose economic survival is directly related to their need for plastic in daily life. This also points to the complexity of systems within systems: multiple independent systems comprise part of a larger and more complex system.

The fifth characteristic is that these problems are not suitable for study through trial and error. Trials produce consequences that may create additional concerns further compounding the problem and the consequences cannot be nullified; therefore, "every trial counts."[176] Sixth, the number of solutions or approaches to a wicked problem has no end because there is no determinate set of rules which means that all circumstances that can occur.[177] These highlight the complexity and uncontained boundaries of wicked problems where trials can spawn additional problems and the lack of defined rules makes a singular solution impossible.

The seventh and eighth characteristics of wicked problems are that each is essentially unique and each can be thought of as a symptom of another problem.[178] In this context, marine debris is unique: there is no other global problem like it – it has no one source, it is uncontained, unconfined, and easily transported; it appears in many forms, it is characterized by both known and unknown consequences, and the majority of the material is found in ungoverned waters. Marine debris can be considered a symptom of global economic pursuits since the proliferation of debris has coincided with the global demand for cheaper and more

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[176] Ibid.

[177] Ibid., 164.

[178] Ibid., 164-65.

disposable materials. Similarly, marine debris challenges the governance of the global commons since regulatory authority is difficult, at best, to define and enforce, once again signaling the interrelated feature of complex systems of systems.

The final two characteristics are that the manner in which a wicked problem is described defines its possible solutions[179] and for the planners who are presenting solutions to wicked problems, they "have no right to be wrong."[180] This speaks to the responsibility governance has to take action on marine debris. Depending upon the viewpoint (sub-national, national, supra-national) marine debris is framed differently, therefore, the possible solutions are proposed without uniformity. Yet, the obligation of governance is to take corrective action because the consequences "matter a great deal to the people who are touched by those actions."[181]

Marine debris, in the context of a wicked problem, can be described in C. West Churchman's (a noted wicked problems scholar) terms as a social system problem that is often confusing for both its multiple clients and decision makers who may hold conflicting values.[182] Meanwhile, the ramifications of marine debris within the ocean system are often diverse and perplexing. Rittel and Webber, as well as Churchman, assert that even trying to tame a wicked problem presents difficulties because only a piece of the problem is addressed, thereby leaving the untamed portion to fester and likely compound. In the case of attempting to contain and collect marine debris, physical containment options along the coastline may create barriers to

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[179] Ibid., 166.

[180] Ibid.

[181] Ibid., 167.

[182] Churchman, "Wicked Problems," B141.

navigation while collection apparatus in the open ocean, such as nets, run the additional risk of trapping and potentially killing marine organisms, most notably fish, turtles, dolphins, rays, sharks and whales. The convolution of marine debris is exacerbated by variables that results in cyclical degradation of the marine environment and, if more aggressive balancing action is not taken, will reach a point where it can no longer be reversed.

The complexity of such a problem renders it very challenging to understand. The remainder of the chapter presents an initial attempt to model the complex and adaptive system that is the wicked problem of marine debris.

System Dynamics

There are two primary reasons why modeling and simulation is employed. One reason is for the purpose of solving a specific problem and the other is to gain a better understanding of the system itself. Not all problems can be solved, but increased insight informs all actions that impact the problem. Increasing understanding by designing a model to aid in the visualization of the wicked problem of plastic marine debris is the goal of this study. Though not solely quantitative, this model provides insight “into the dynamics underlying behavior, into the processes that result in the observed correlations, and into the way in which multiple factors come together”[183] and create specific conditions. The model offers a framework for a broadly defined system whose approximations are observable through repeated iterations of the system’s simulation.

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[183] Carley, "Computational Approaches to Sociological Theorizing," 69.

As systems - natural or human-made – change, they often become complicated and difficult to manage leading to a quest for a method to aid in the understanding and design of the system that can facilitate its improved management. System dynamics provides such a tool becuase it "is a modeling method used to study complex systems in a methodical manner."[184] It models associations and interactions among components in a given system through the compression of time and space, and elucidates the influence of the relationships on that system over time. This enhances understanding of a complex system and presents opportunities for improved system designs. At the same time, modeling serves as a pragmatic heuristic stratagem for the development and refinement of policies aimed at improving a designated system.[185]

The field grew from the initial work of Jay W. Forrester and his writings on dynamics in an industrial setting in the 1960s. While the tendency is to look for isolated causes and effects, Forrester's approach challenged students, researchers and designers to look at the organization of the whole system to include the system's variables. Originally designed to aid in the understanding of industrial management challenges, System Dynamics has expanded extensively in the intervening years and is now commonly applied in areas such as economics, environmental studies, public and foreign policy, defense, and a wide spectrum of the social sciences.

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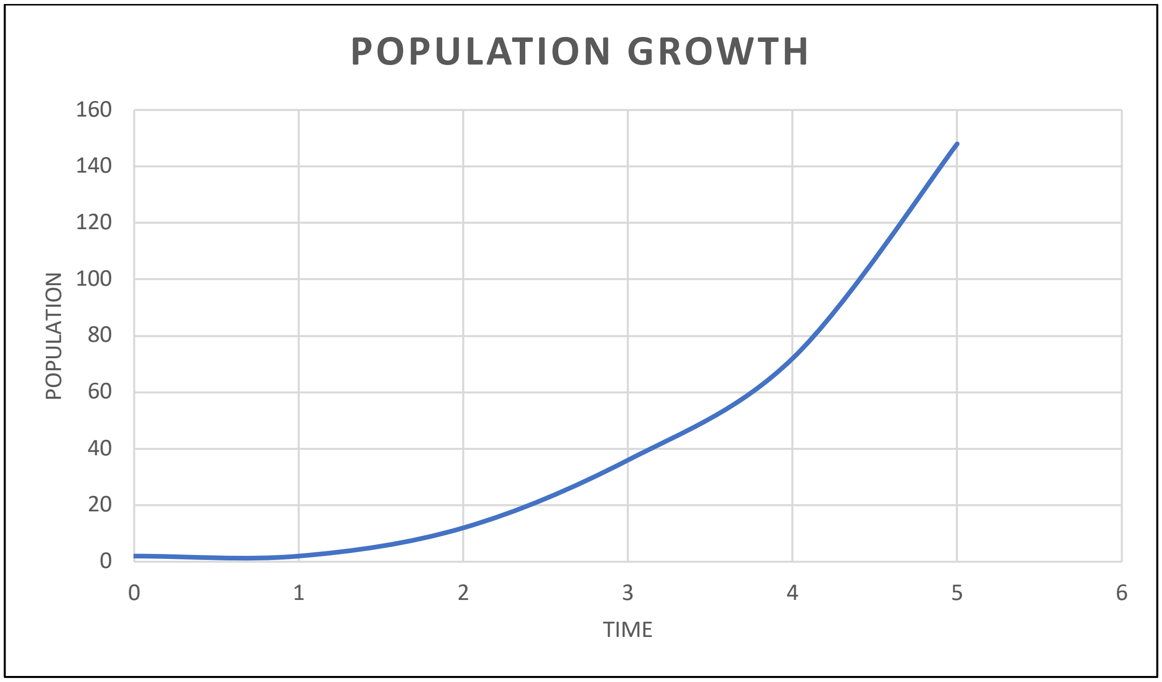
[184] John A. Sokolowski and Catherine M. Banks, *Modeling and Simulation for Analyzing Global Events* (Hoboken: John Wiley & Sons, Inc., 2009), 45.

[185] John D. Sterman, *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Boston: McGraw Hill, 2000), vii.

Systems are comprised of variables, some more dominant than others, and system complexity is created from and intensified by the interaction of these variables. This interaction, (more specifically, actions and reactions) in a system is known as feedback and has both positive and negative elements. The first feedback element is entirely positive or negative, and the rate of increase or decrease in a variable compounds over a period of time as the behavior in the system accelerates its growth. This is one of the primary behaviors of a dynamic system known as "exponential growth." (For the purposes of this study only three will be utilized as they best provide contextualization.) As an example, exponential population growth over time is illustrated in Figure 4.1. When resources are unrestrained, populations have nothing that will hinder their growth and thus will demonstrate exponential growth over a given time period.

Figure 4.1

Exponential Growth of a Population



Conversely, the second feedback element counters or "balances" the behavior, producing limitations or even reversing it in some instances. This is also referred to as "goal-seeking" which represents the system continuing to grow or decline, however, it begins to level off as it approaches a particular value.[186] An example of "goal seeking" is illustrated with population growth over time in Figure 4.2.

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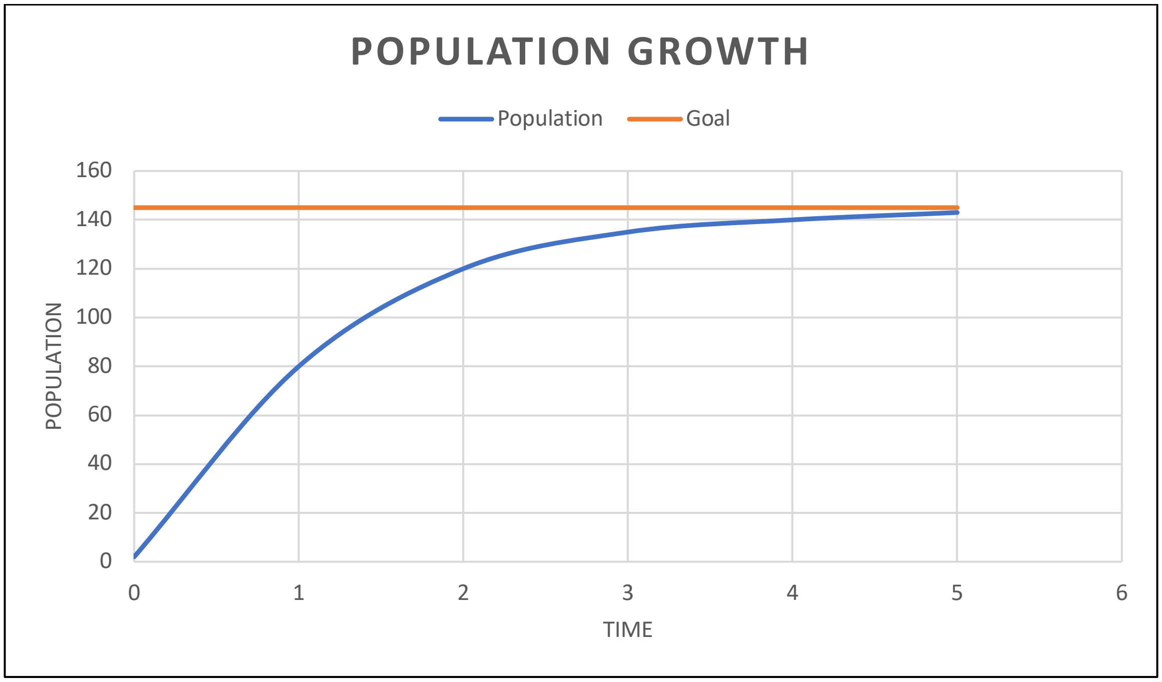
[186] Sokolowski and Banks, *Modeling and Simulation for Analyzing Global Events*, 46-47.

Figure 4.2

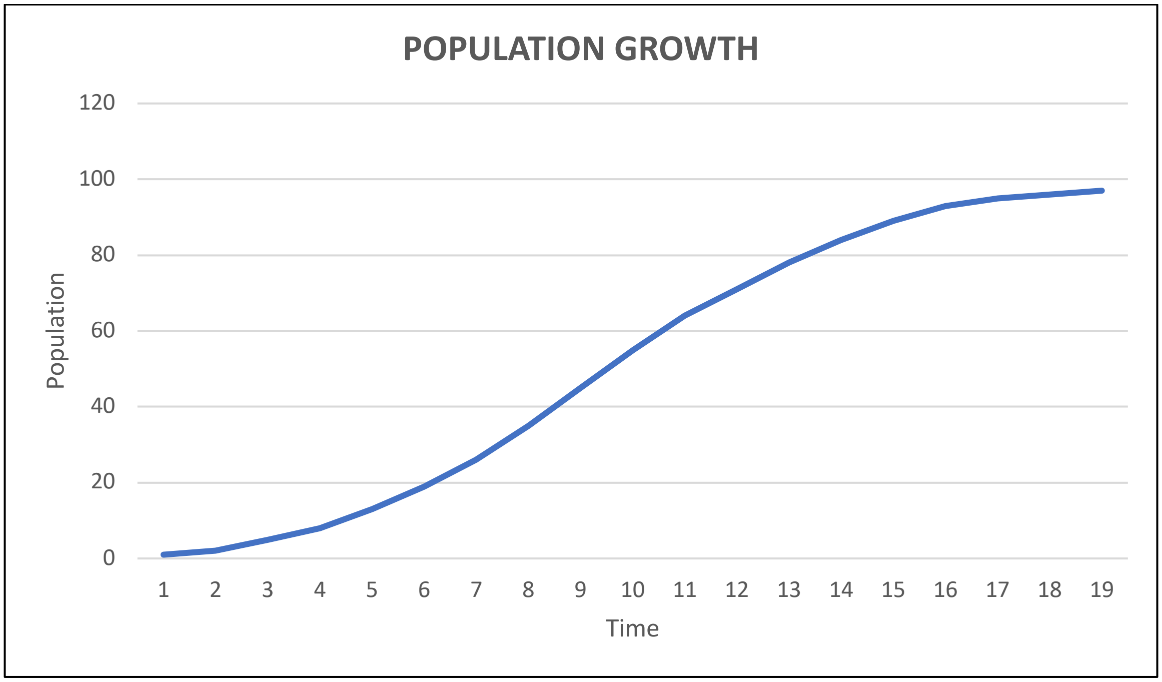
Goal Seeking Population



The third feedback element starts with positive (exponential growth) and then negative (goal-seeking) influences start to dominate creating a dampening effect on the growth. This demonstrates how the system overcomes the positive feedback and is denoted by an S Curve. S Curves represent a system that approaches a goal but, due to damping effects in the system, never quite reaches that goal or, if it does, it does not exceed the goal. An example of an S Curve is illustrated with population growth over time in Figure 4.3.

Figure 4.3

S Curve of Population



In order to frame a problem and identify potential positions of influence, proper visualization of the system and its variables is essential. A principal method utilized in system dynamics employs a model known as a causal loop diagram (CLD), also sometimes referred to as a feedback loop. A CLD is a qualitative method that demonstrates variable relationships in a system by defining variables that influence how a system behaves and how those variables are interconnected with one another. Furthermore, it shifts understanding from a linear to a circular cause and effect concept. By selecting a key variable and illustrating the influences of other variables, a CLD provides insight into the operation of a system known as feedback. This can then be communicated to those that analyze policies, to improve designs and ultimately implement more effective and sustainable solutions.

In a linear cause and effect diagram, problems or relationships are described in a manner in which a cause creates an effect and the diagram ends at that point. An example would be that of a basic problem (cause) in which an action (effect) is taken and thus solves the problem. Conversely, in a CLD example, a problem initiates action that feeds back into the problem and thus creates a continuing loop. A CLD contains both points that represent variables and arrows that connect the points within a given system. The lines describe properties of variable relationships; the arrows further aid in understanding the flow and influences of the relationship. When variables change in the same direction (when one increases, the other increases or when one decreases, the other decreases) this indicates a positive relationship exists between the variables which tends to reinforce the interaction in the system thus providing positive feedback - reinforcing loops. Conversely, when variables change in opposite directions (when one increases, the other decreases or when one decreases, the other increases) this indicates a negative causal link exists between the variables which tends to counter the interaction in the system thus providing negative feedback and are termed balancing loops.

Reinforcing and balancing loops are key features in a CLD. They provide visualization for understanding the forces at work within the system. If a diagram contains a reinforcing loop, one can determine that the variables have a similar effect on each other, either both positive or both negative, and thus will continue to move in the same direction over time, reinforcing a pattern. Meanwhile, if a diagram contains a balancing loop, one can determine that the variables within the loop have both positive and negative effects thus indicating that while the actions may not balance 100 percent and reach a steady state, they do exert some offsetting effect on the problem that limits its growth through some measure of reduction.

As with all CLDs, the extent to which one can aid in comprehending the functionality of a system depends upon two principal steps regarding how the model is constructed. The first is the establishment of the system's boundaries that limit the size and focus of the CLD. This is accomplished through a determination of what variables are internal (the focus for the model) and external to the system with any necessary justifications for those boundaries established. Once this is accomplished, the second step is to create the relationships among all the variables in the model and provide any necessary justification for those relationships.

Plastic Marine Debris Causal Loop Diagram Setup

The application of a system dynamics causal loop is an excellent tool to help understand effects of plastic debris in the marine environment because it views the problem from a system design standpoint. Designing an ocean plastic system from a technical approach illuminates the functions that either reinforce or balance the positive and/or negative impacts of plastics in the ocean dependent upon the defined boundaries.

In order to set up a causal loop, four principal variables were selected. The first is "Global Plastic Production" (GPP) which equates to the global production levels of relatively inexpensive, versatile, lightweight synthetic polymers derived from fossil fuels. It is assumed that this variable represents, in large part, virgin plastic (first production from original fossil fuel derivation) although a very small portion of GPP is salvaged and reprocessed. Next is

"Consumption" that represents the acquisition of goods and services during a particular period of time to satisfy human wants. Stimulants and depressants associated with consumption are varied and debated but often include wealth or the lack of it and movement in terms of trade. The third key variable is plastic "Waste" defined as plastic material that is not wanted - the unusable remains or byproducts of plastic generated from both manufacturing and consumption. The majority of this Waste goes to landfills or is disposed of improperly and ends up in the ocean.[187] According to research "approximately 6,300 Mt [metric tons] of plastic waste had been generated"[188] as of 2015. The final key variable is the dependent variable – a problem that results from the effects of plastics in the ocean - which is termed "Threat to Ecosystem." This is the possibility that an undesirable action associated with plastic marine debris will occur, often resulting in harm to a complex network of interconnected systems frequently related to organisms and their physical environment, in this case the marine environment.

In addition to these four principal variables, ten auxiliary variables are deemed strong influencers on the plastic marine debris system and are part of or inside the system. The first is "Availability" which refers to a resource that is accessible for use when demanded for consumption or to perform a required function. Next is "Trade" which is the means by which the transfer of goods and services is enabled. On an international level, Trade promotes the expansion of markets in both areas whereas those goods and services may have been limited or unavailable entirely had international trade not provided such opportunity. With its roots in

[187] O'Neill, *Waste*, 39.

[188] Jambeck et al., "Plastic Waste Inputs from Land into the Ocean," 1.

Adam Smith's *Wealth of Nations (1776)*, open and freer trade has generally been seen by economists as beneficial for an economy which lends to the third variable, "Economic Growth." Economic Growth compares one time period to another, during which an increase in the production of economic goods and services is observed.

The fourth auxiliary variable is "Versatility," defined in this context as easily used for many purposes. In the context of goods, versatility affords a manufacturer less expenditure on the procurement of the base material that can produce multiple different forms of plastic, less industrial infrastructure to manipulate only one base material, and greater opportunity to provide multiple plastic products to customers. The fifth auxiliary variable is "Cost" or the amount that is incurred by a manufacturer for a product. Such costs generally encompass raw materials and labor and can include amortization of the manufacturing equipment used in making the product. The cost it takes to manufacture a product directly impacts the purchase price and the profit earned from the product's sale.

The sixth auxiliary variable is "Environmental Regulations," rules generally put in place by a state to protect the environment in regard to issues that may, or do, cause harm. An example of a US domestic environmental regulation is the Microbead-Free Waters Act of 2015 which prohibits the manufacturing and distribution of rinse-off cosmetics containing plastic microbeads. "Recycling" is the seventh variable and refers to the process of recovering scrap (or waste) plastic, then submitting it to a special reprocess cycle that transforms it back into functional or useful products. Eighth is "Solid Waste," the dominant portion of plastic waste that is still in some solid form, and the ninth is "Toxins" which the US Environmental Protection Agency describes as any substance that may be harmful to the environment or hazardous to health if inhaled, ingested or absorbed. An example of a toxin is the insecticide DDT, heavily used in the 20th Century until adverse effects on both humans and wildlife became well-recognized and was subsequently banned in the US in 1972, and in several other countries around the world. However, as with numerous other toxins, DDT is not easily biodegradable lending to its accumulation in soil and its runoff into rivers and the ocean. While toxins are noted for their immediate danger, this also illustrates the potential of their lingering deleterious effect on humans and the environment. The final variable is “Awareness,” used in this context to represent both governmental and public interest in and concern about plastic impacts on the marine ecosystem.

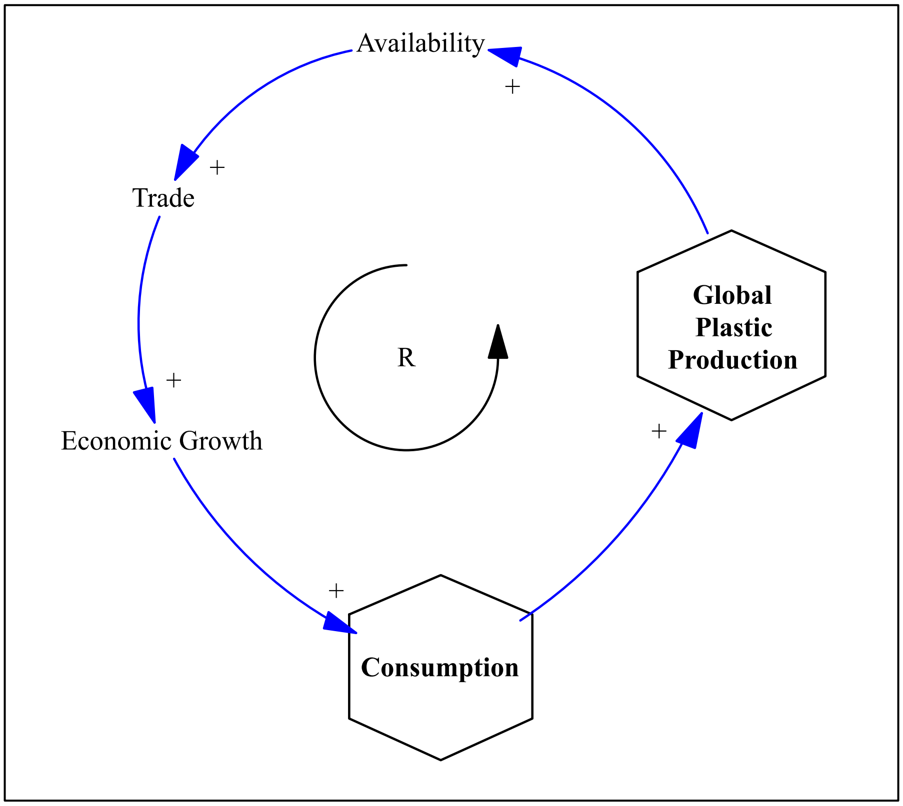
Meanwhile, numerous other variables, such as wind and currents, could potentially interact with and influence the system. While this is true, the lens through which this analysis views variables focuses on crucial human variables; hence, other factors such as wind and currents are considered to be outside the system central to this study.

Global Plastic Production and Consumption

Utilizing each of the variables, arrows depict their connectivity and influence. This first phase in diagramming the effects of plastics in the marine environment (Phase I) begins with the key variable Global Plastic Production (GPP) and is depicted in Figure 4.4. The indefinite life of plastics and the resultant problems begin with manufacturing.

Figure 4.4

Phase I of Depicting Plastics in the Marine Environment via a CLD



As mentioned in Chapter 3, plastics are made of polymers - long, flexible, lightweight and durable chemical compounds derived from fossil fuels whose production currently exceeds 300Mt per year. With the production of plastic, the product that is generated increases output and thus creates Availability of plastic products to the supply chain and ultimately to consumers, therefore, GPP has a positive effect on Availability noted by the "+" mark (and henceforth represented in all diagrams in the same manner) on the arrow from GPP to Availability. However, GPP and Availability require a means of exchange, which is facilitated by

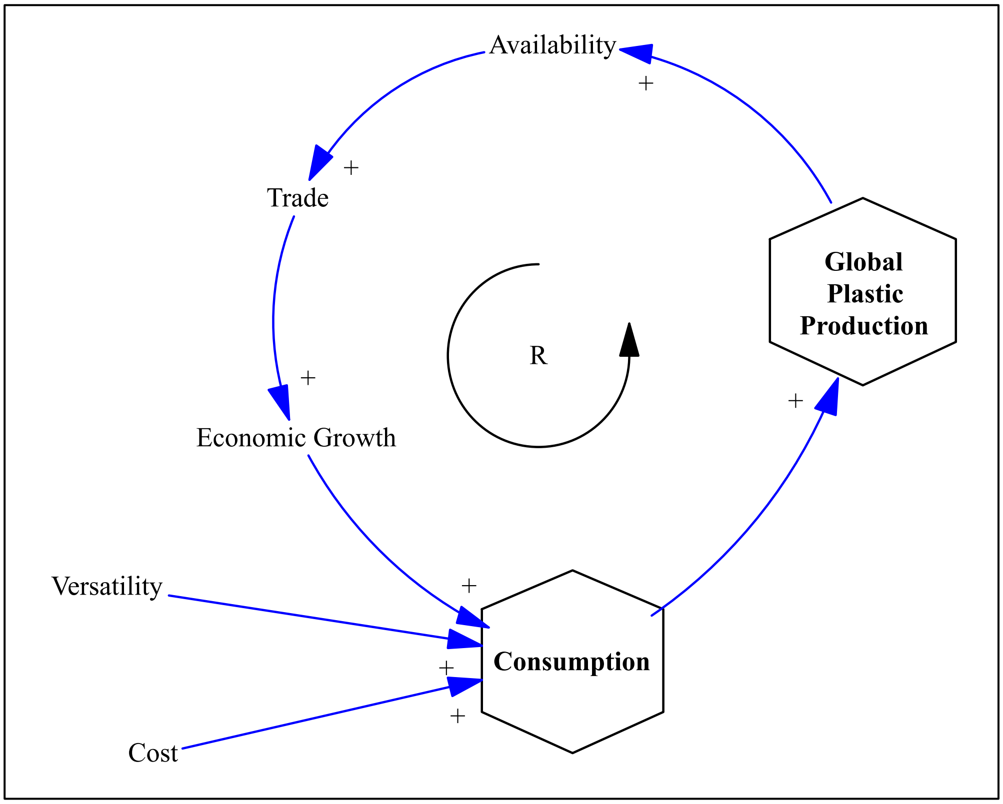
Trade. With the development of a product that is made, Trade is enhanced, thus similarly, GPP and Availability have a positive effect (+) on Trade. If one were to think of Trade as a moving mechanism, without a commodity such as plastic, Trade would be stagnant, but when plastic is produced, Trade then has a commodity to propel through its mechanism, so plastic has a positive effect (+) on Trade.

Continuing with the development of this loop GPP, Availability and Trade aid in the stimulation of Economic Growth. Once again, the principal component is output, but when that output becomes locally available and then is dispersed through trade expanding its availability domestically and internationally, Economic Growth is enhanced, therefore, GPP, Availability and Trade have a positive effect on Economic Growth. The positive effects of each variable thus far, render plastic commodities readily accessible for the second key variable Consumption; therefore, a positive effect (+) on Consumption is assigned. The loop is closed when Consumption of plastic products reduces the volume, creating more demand and driving continued GPP in an exponential growth pattern - a positive effect (+) on GPP. Since each variable helps drive the next without any offsets this is deemed to be a reinforcing loop indicated by the “R” in the center of the loop. The curved arrow or loop surrounding the “R,” which indicates a counterclockwise direction, distinguishes the reinforcing loop and the direction of flow through the variables and is shown as a large curve arrow to correspond with a strong reinforcing effect on this portion of the system.

Two additional variables that substantially contribute to Consumption in this loop are Versatility and Cost, depicted in Figure 4.5. One of the most appealing

Figure 4.5

Phase I Including Versatility and Cost



aspects of plastics is their versatility of form and function since modern plastics are made of polymers that can be constructed and shaped into numerous sizes, shapes, and thicknesses. Furthermore, due to their low density, their durability, and their excellent barrier properties, they have become an extremely versatile product for manufacturing and packaging applications from medical equipment to automobiles parts to food and drink containers.[189] No other

[189] Peter G. Ryan, "A Brief History of Marine Litter Research," in *Marine Anthropogenic Litter*, ed. Michael Klages, Lars Gutow, and Melanie Bergmann (Springer, 2015), 2.

product on the market today possess the applicability to most every global industry that plastics do, thus Versatility is deemed a positive effect (+) on Consumption.

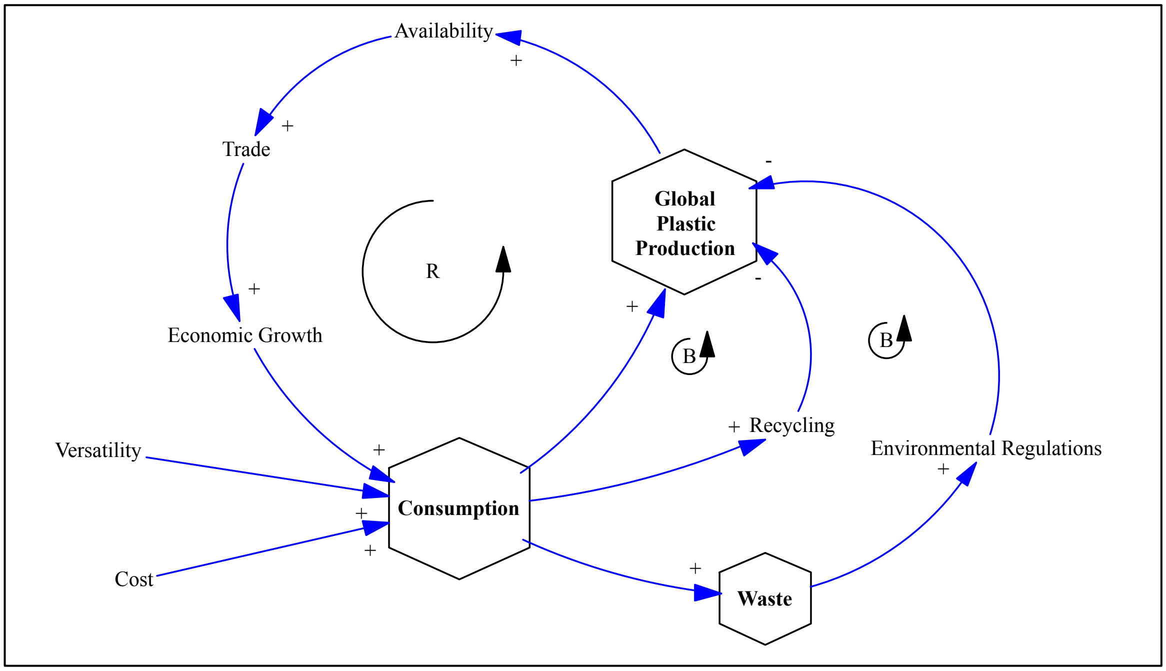
Meanwhile, plastics are less expensive to manufacture than other comparable products such as glass, cardboard and metal. The raw materials from which most plastics are derived are crude oil and natural gas; more specifically their by-products created during the refining process are hydrocarbons such as propane and ethane. These are collected and further processed to create plastics. As such, these by-products require little initial financial expenditure since there is already a sunk cost in the refining process designed around the principal product (diesel, gasoline and pure natural gas.) This alone is seen as a positive effect on Consumption. Furthermore, due to their lightweight flexibility, plastics afford manufacturers an opportunity to quickly make products via injection molding that would take significantly longer and thus increase production costs for other materials. These two variables create the ubiquitous plastic desired by and available to consumers and have a strong positive effect on Consumption.

Waste

The second phase in diagramming this system (Phase II) is the incorporation of the key variable Waste as shown in Figure 4.6. The two key variables of GPP and

Figure 4.6

Phase II of Depicting Plastics in the Marine Environment via a CLD



Consumption both produce Waste. Starting with the production process, waste plastic is generated in many forms such as excess products with imperfections not acceptable for use. These products are often considered a write-off as part of doing business and the flawed production material is simply discarded. GPP also generates a large amount of excess material in the form of shavings which are created after a plastic product is removed from molds. Some of this material breaks off around edges where overflow has occurred during the molding process while even more is intentionally filed off during the polishing phase to ensure a smooth product. Then there is the issue of early stage production spillage. This refers to hundreds, even thousands of nurdles that are lost in the production process. These pre-production plastic resin pellets are susceptible to spillage during transit to factories, transfers from delivery trucks at the factory and conveyance along manufacturing lines within the factory. Additionally, excessive plastic packaging is used during the late stages of the manufacturing process due to its light weight, versatility, and low cost - characteristics which would otherwise limit plastic use as happens with more costly and less versatile materials such as glass, metal and wood.

GPP Waste is driven by the other key variable, Consumption, and is therefore not singled out by a separate arrow. Instead, Consumption, as the primary driver of Waste, has a positive effect on Waste. It creates the circumstances and demand for low Cost, Versatile plastic products. Often due to their low Cost, excessive materials are used – most notably in packaging. For example; almost any grocery store in the United States displays a significant portion of produce packaged in plastic bags or individually wrapped in plastic, not to mention the rolls of plastic bags conveniently placed in the produce section for shoppers to place bulk items in without further consideration. A similar situation repeats itself throughout the rest of the store where one will find items from meat and poultry, to bread (both fresh and factory-produced) and most dairy items all packaged in plastic. Each of these items, with the exception of the freshly baked bread (although their base products are not excluded), have usually made their way to the store wrapped in at least one layer of plastic. Since these items of plastic are designed for packaging, they have a one-time use and are then discarded.

While excessive packaging and single-use items such as plastic food and drink takeout containers are easily noted as Waste generators, less obvious items such as medical products (syringe tubes, intravenous fluid bags, hospital bedframes, machine casings), automobile parts (interior lining, bumpers, cable insulation, instrument panels, weather proof coating) and common household materials (cleaning solution bottles from laundry detergent to glass cleaners to hand soaps, PVC shelves, storage bins, garbage bins and toothbrushes) all usually contain a large amount of plastic and are eventually discarded into the waste stream. Due to its durability, flexibility, low cost and versatility, plastic has become ubiquitous and thus makes a steadily increasing contribution (positive effect) to the key variable Waste. In their 2017 Science article, Geyer, Jambeck, and Law estimated 8.3 billon Mt of plastic had been produced resulting in 6.3 billion metric tons of waste. They estimate of that waste, 79% was "accumulated in landfills or the natural environment,"[190] demonstrating the significant percentage of plastic that ends up as true Waste.

Geyer, Jambeck and Law accounted for the remaining 21% of plastic waste through incineration (12%) and recycling (9%).[191] While incineration does dispose of the plastic permanently, it potentially generates hazardous toxins and air pollution in the process. On the other hand, because Recycling is an avenue that affords an opportunity to collect, clean, reprocess and generate new plastic-based materials, it should have a negative or balancing effect on GPP (in the sense of virgin plastic) and would be representative of a goal-seeking curve. However, there are numerous challenges to Recycling from proper and sufficient collection facilities, to contamination of the recycling stream, to the basic economics of weak or no profitability in Recycling. Unfortunately, a paltry amount of plastic is completely recycled and thus characterized by a very small balancing loop.

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[190] Jambeck et al., "Plastic Waste Inputs from Land into the Ocean," 1.

[191] Ibid.

Similarly, the generation of vast amounts of Waste has prompted measures to be taken that impose Environmental Regulations to address the negative effects. Regulatory actions such as the 1972 London Convention and the 1996 London Protocol specifically address the marine environment and are designed to restrict pollution produced by the dumping of wastes into the ocean which reflects a balancing loop on GPP. Yet, there are only a limited number of such regulations and those in place are inadequate to address all aspects of plastics entering the ocean. In fact, the London Convention does not address discharge from landfills, manufacturing plants and other land-based sources that generate the majority of plastic marine debris. Without an enforcement mechanism, measures such as those currently in place are reliant upon the good faith of individuals, multinational corporations, states and others who may succumb to economic pressures or the simplicity of convenience. This is representative of an S Curve that demonstrates how the system might overcome the positive feedback and could approach a goal of significant marine debris reduction; however, due to damping effects it does not reach that goal. Therefore, as with Recycling, Environmental Regulations are limited in their significance and are denoted with a very small balancing loop.

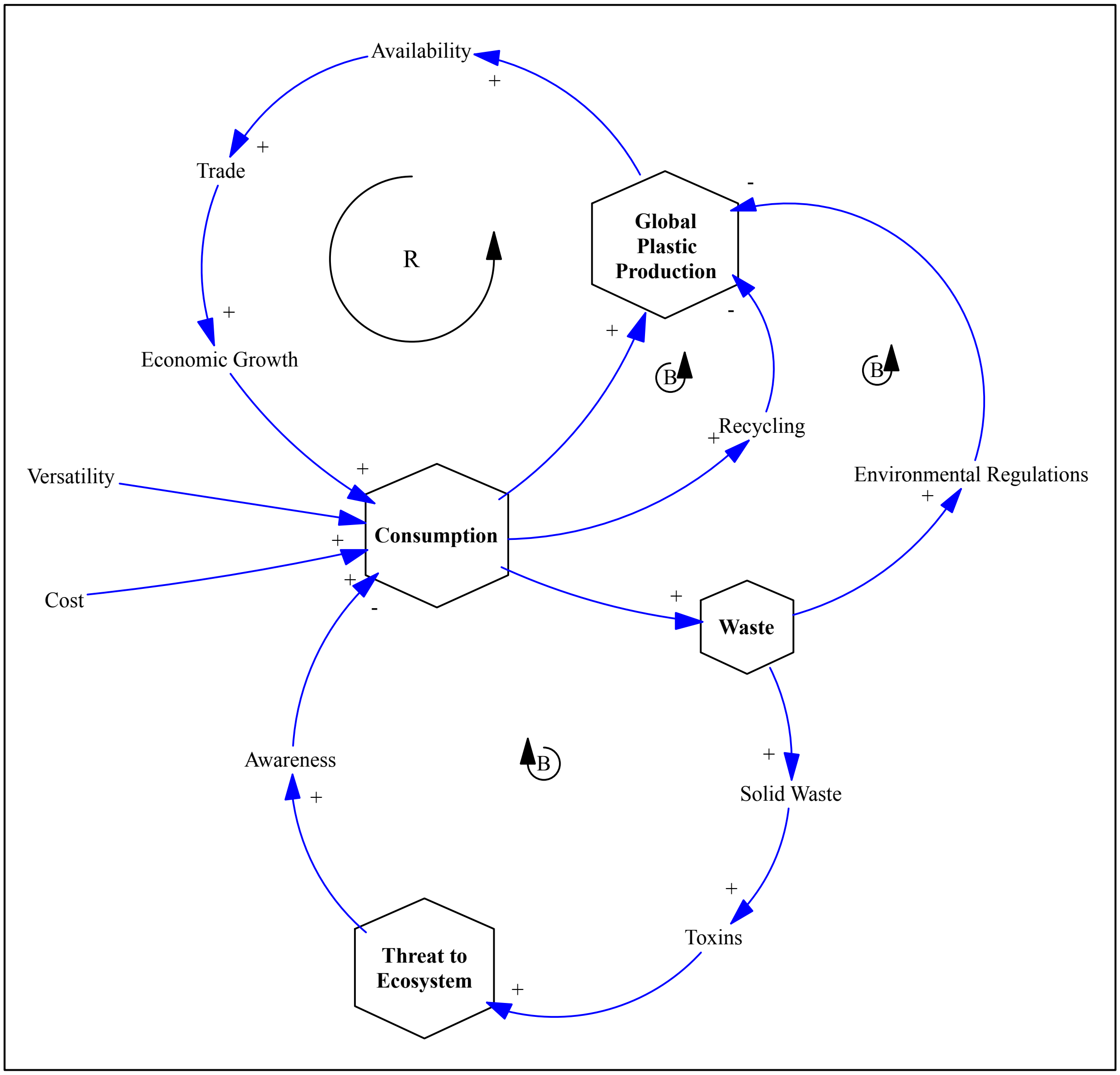
In fact, based on the scale of plastic production, Recycling currently has little to no noticeable impact on GPP. While the same can be said for Environmental Regulations, they do possess the potential for growth and the eventual development of a solid balancing effect on the system.

Threat to Ecosystem

The final phase in diagraming this system (Phase III) is the incorporation of the key variable Threat to Ecosystem as shown in Figure 4.7. As previously identified,

Figure 4.7

Phase III of Depicting Plastics in the Marine Environment via a CLD



Consumption produces Waste in several forms but for the purposes of this model it will be characterized as two specific forms – Solid Waste and Toxins. Solid waste is defined as plastic which is either in its original configuration or a tangible sub-structure (bottles, bags, nets, broken pieces of containers, microplastics and nanoplastics.) Solid waste is most notable for its devastating effects on marine wildlife. As mentioned in Chapter 2, turtles, whales, dolphins, fish, and seabirds all consume plastic, mistaking it for food. This can lead to strangulations, amputation, infection and starvation since plastic in the gut implies the stomach is full, yet it provides no nutrition and is not passed through the system to make way for proper nutritional consumption. Marine wildlife suffers from entanglement in plastic material that generally leads to death from lacerations and injury that result in infection and/or impede their ability to swim or fly.

Marine debris also provides an avenue for transport of invasive marine species. Such species attach themselves to plastics in the ocean and, due to their lightweight composition, plastics are easily conveyed by waves, wind and currents across vast areas of ocean to coral reefs, polar ice regions and major commercial ports where the introduction of such species can alter the delicate balance of a local ecosystem. For these reasons, Solid Waste has a positive effect on the threat to the marine ecosystem (Threat to Ecosystem).

Plastic also produces toxins in the initial manufacturing process but primarily as a waste product. Since plastics do not biodegrade, those that enter the marine environment eventually break down and emit toxins from the original chemical process that created the plastic material. Degraded water quality affects marine ecosystem health and safety. Plastics are also likely to contain residual materials which provide a bed that promotes the growth of bacteria. The growing presence of bacterial contamination including E. coli, viruses, neurotoxins and heavy metals that can be found in these waters harms the health of the marine ecosystem and humans who rely on it. Human consumption of or contact with water polluted with these contaminants and pathogens can result in infectious hepatitis, diarrhea, bacillary dysentery, skin rashes, and even typhoid and cholera.[192]

As previously mentioned in Chapter 2, plastics are both a consumer and a producer of toxins and, absorb contaminants at an extremely high rate of efficiency. This generates cause for concern since toxins are emitted into the marine ecosystem during plastic breakdown. While there is limited literature on toxin emissions from plastics in the ocean, a 2019 study by Lisa Zimmerman et al, on the toxicity of plastic consumer products showed that of 34 common plastics (that cover a range of product categories and chemical properties), 74% contained chemicals that triggered at least one toxic or damaging outcome: "including baseline toxicity (62%), oxidative stress (41%), cytotoxicity (32%) [toxic to cells], estrogenicity (12%) [promoting estrus], and antiandrogenicity (27%) [blocks testosterone]."[193] Though the amount of toxins emitted by plastics into the ocean in large part dispersed and, when compared to the volume of the ocean, is likely to be rather small, the indications from the Zimmerman study coupled with rapidly increasing volume of plastic in the ocean provides a valid concern for a Threat to Ecosystem, thus having a positive effect.

Over time, the marine threats from solid waste have become evident to recreational boaters and divers as well as researchers, commercial fishermen and ocean transport companies. More importantly the mainstream media has recently helped increase awareness

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[192] Sheavly and Register, "Marine Debris & Plastics: Environmental Concerns, Sources, Impacts and Solutions," 302.

[193] Lisa Zimmermann et al., "Benchmarking the in Vitro Toxicity and Chemical Composition of Plastic Consumer Products," *Environmental Science & Technology* 53 (2019): 11467.

of the problem on a growing but small scale, thus Threat to Ecosystem has a positive effect on Awareness. As with the increasing Threat to Ecosystem presented by Solid Waste, Toxins in the marine environment should also generate increased Awareness and create a balancing loop representative of a goal-seeking curve, although all indications are that while awareness is increasing it still remains small in regard to the balancing effect it currently imparts. Unlike Solid Waste though, the effects of Toxins in the ocean are not easily identifiable, making them less tangible. This translates to extremely low Awareness and a small balancing loop. However, with increased Awareness, which spreads information concerning the prevalence of marine plastics and its risk factors, behavior can change, leading to a reduction in Consumption; therefore, Awareness is denoted as a negative impact on Consumption.

Regardless of the current impact on balancing, and similar to Recycling and Environmental Regulations, Awareness has the potential for expansion that leads to a solid balancing effect on the system.

Takeaways from the Causal Loop Diagram

The steps taken to lay out a phased development of the plastic marine debris system provide a computational model that more accurately conceptualizes the relationships within the system and further helps understanding the implications of the system's behavior through its heuristic character. In Phase I, a strong reinforcing loop is evident where the system variables continue to compound the growth of plastic marine debris through supply and demand. More specifically, manufacturing provides a product that enhances economic growth through trade, widespread availability, product versatility and low cost for consumers. This translates to unchecked consumption that results in a rate of increased demand for more global plastic production that compounds over time. This, in turn, causes the behavior in the system to accelerate its growth representing a strong positive feedback associated with an exponential growth curve.

Phase I incorporates several of the characteristics of a wicked problem. It does not have a definitive formulation because there are different interpretations associated with the importance of each variable and how the impact of each variable contributes to a potential solution. In Phase I, none of the variables contribute to a solution, but differing judgments and perceptions of the system could suggest otherwise. Adjustments to this system which could lend to a potential balancing effect might also create other consequences over an expanded period of time and space, yet because there is no way to track every consequence, a definitive test does not exist for a solution to this problem.

Phase II offers a potential goal-seeking curve with balancing properties, yet it is impacted by dampening effects and thus results in an S Curve. Consumption generates a tremendous volume of plastic waste while it simultaneously creates an opportunity for containment and reutilization through a recycling stream which introduces a balancing effect. Waste also stimulates efforts to address environmental concerns triggered by compounding problems associated with plastic entering the environment. This spawns environmental regulations that, like recycling, introduce a balancing mechanism to the system. Unfortunately, both recycling and environmental regulations' potential for balancing has been dampened for numerous reasons.

In the case of recycling, the process requires consumers to properly dispose of plastics in designated recycling bins, where the disposal depends on the type of plastic resin in the product. This creates confusion for many consumers regarding separation and proper recycling, often leading to frustration and foregoing the process entirely. Meanwhile, the collection and processing companies must sort, shred, wash, melt and pelletize the plastic for reuse. While this does not necessarily imply an overtly difficult task, it is actually quite complicated and challenging since plastic recycling bins are often contaminated with general waste, other non-plastic recycling materials, or are extremely dirty. Each of these significantly impedes the recycling process. In many cases, when contamination of plastic recycling is significant, the entire batch being rejected and either sent to incineration or to landfills which alleviates some of the challenges to marine debris but also generates other problems. These challenges reduce the economic incentive to run a recycling facility which make it less commercially enticing and results in declining options for Recycling thus dampening this variable and considerably limiting its balancing effect.

Similarly, environmental regulations have been created, primarily at a state level, but they are limited in scope and therefore in their ability to have a considerable balancing effect, especially at the global level. With the limited efforts of substantial regulatory measures from a wholistic (global) approach, the balancing effect results in little more than a trickle compared to the flood of plastic entering the ocean. One could envision the slight balancing effect associated with environmental regulations turning positive because governments and international bodies could ease these already limited regulations, so the negative effect becomes less and less, eventually even turning positive in a worst-case situation. A recent turn of events may produce these conditions given the United States' announcement of its intention to pull out of the Paris climate accords, with similar intentions stated by Brazil. This predicts a scenario of a reversal in these loops under certain conditions. The reversal could take place as applies to Recycling since it is limited and many of the contracts are ending and facilities are closing. At the moment few alternatives exist. So, if in fact the opportunities to recycle continue to disappear, Recycling may cease, thus producing a reversal into a positive feedback loop.

As with Phase I, Phase II underscores several characteristics of a wicked problem. Interpretations associated with the importance of each variable and how the impact of each variable contributes to a potential solution vary, inhibiting a definitive formulation. Adjustments to this system that may lead to the reversal of the loops would most certainly create other consequences.

Phase III demonstrates a feedback loop analogous to Phase II in that it offers a potential goal-seeking curve with balancing properties, yet it is impacted by dampening effects and thus results in an S-curve. As noted in Phase II, Consumption breeds a vast amount of plastic waste, but in Phase III, Waste generates both a direct and indirect threat to the marine ecosystem. Plastic waste emanates in numerous forms lending to a variety of means by which it can threaten this ecosystem. As previously addressed, some of the direct threats of solid waste include ingestion, suffocation and entanglement of marine species. Scholarship on this point is growing rapidly and expanding to note additional threats such as those associated with endocrine disruption – the reproduction system in marine species. Correspondingly, toxins, emitted from plastics, predominantly during plastic breakdown, also heighten the threat to the ecosystem. While some may argue that, due to the size of the ocean, the small amount of toxin emitted when pieces of plastic breakdown currently has a negligible effect due to toxin dispersion, this study contends that any toxins emitted simply compounds the issues already threatening the ecosystem. As such, both components of Waste that contribute to Threat to Ecosystem produce a positive effect on the Threat to Ecosystem.

Meanwhile, in recent years Awareness of the growing problem of marine debris and the threats it presents to the marine ecosystem has increased and produced a slight balancing effect. Unfortunately, Awareness has been tempered due to characteristics of its wickedness render interpretations of the system are very subjective. Adjustments to this system, which could increase the potential balancing effect, might also create other consequences. There is no definitive test for a solution to this problem which illustrates that plastic marine debris is essentially unique. It can be thought of as a symptom of another plastic problem such as over production, practically boundless consumption, limited recycling, and few and ineffective environmental regulations. Each of these imposes a strong dampening effect on the balancing potential of Awareness producing an S Curve that does not afford the negative input of Awareness the opportunity to reach the balanced goal. Therefore, Phase III can be viewed as one where the increasing risk of Solid Waste and Toxins on Threat to Ecosystem appears to significantly limit the impact of Awareness on the effects of balancing at this time.

Finally, in this system, few variables are directly tied to the dependent variable (Threat to Ecosystem); however, they are all linked to the dependent variable through their connection to each of the key variables (Global Plastic Production, Consumption, and Waste). This model depicts a system that contains several indirect influences with significant impact on what is clearly a dynamic system. Additionally, the effects (subject to alteration) of each variable highlight the complicated undercurrents in the system. The problem that results is a social as well as causal problem, where many of the variables and their actions are mutually informing and demonstrate strong characteristics of a wicked problem.

Conceptualizing marine debris as a wicked problem establishes an atypical framework and affords an opportunity to more accurately grasp this exceedingly complex issue. Under this construct, the further application of a system dynamics causal loop diagram provides greater insight into the complexities that account for the wickedness of plastic marine debris. Consequently, a deeper understanding of these complexities offers new opportunities for managing this existential threat.

CHAPTER V

SIMULATING THE WICKED PROBLEM OF MARINE DEBRIS

"…making simulations of what you're going to build is tremendously useful if you can get feedback from them that will tell you where you've gone wrong and what you can do about it."[194]

- Christopher Alexander, PhD., Professor Emeritus of Architecture, University of California, Berkeley

Plastic Marine Debris Simulation

Heuristics are very useful for conceptualization and as demonstrated by the causal loop diagram, plastic debris is a wicked problem within the marine environment. The efficacy of a CLD is its ability to provide a visual representation of a system that includes exponential growth or balancing effects. Aside from the value this heuristic provides while attempting to conceive of the problem in a unique manner, it also supplies the foundations for the production of measurable outcomes over a period of time when data sets are applied to the variables. These adjustments allow for the transformation of the model from a heuristic into a simulation. The utility of simulation is that it allows for repeated observations of a model through implementation in a temporal manner via computational analysis that reflects potential changes in the system. This "enables the theorist to think systematically and thoroughly about systems that are larger, more complex, have more interactions, have more underlying

[194] Lily Orland-Barak and Ditza Maskit, *Methodologies of Mediation in Professional Learning* (Cham: Springer, 2017), 63.

dynamics, than can be thought through without the aid of such automated accounting devices."[195]

In a stock and flow diagram, stocks are entities that can accumulate or be depleted, similar to a water tank which fills with water from a pipe. Flows are entities that increase or decrease stocks, like a valve on a pipe that affects the level of water in the tank. To better distinguish between the two, modelers often describe them by considering what would happen in the system if time were to stop. The accumulators (stocks) would remain; however, the actors (flows) would vanish. Therefore, when a particular point in time is observed, the stock levels will represent the quantity existing at that point based on the actions of the flows. Consequently, stocks are the variables for which observable changes are sought. A simple modeling representation of this is provided in Figure 5.1 where a stock is represented by a rectangle, large arrows indicate the direction of flow, two triangles connected at their tips represent a valve in the middle of the large arrows which regulates the flow of input/output (flow rate) and thus represent the rate-of-change for the stock, and the cloud shapes at either end of the model represent sources (stock variables outside this system) that feed the system or receive output from this system.[196] When translating the casual loop diagram, previously developed in this chapter, into a stock and flow, the four key variables become the stocks (GPP, Consumption, Waste and Threat to Ecosystem). Each one of these is a dependent variable (DV) since each stock will be adjusted with the flow rate, while the primary focus is on Threat to Ecosystem. Of note, the value of a particular rate is not contingent on preceding values of that

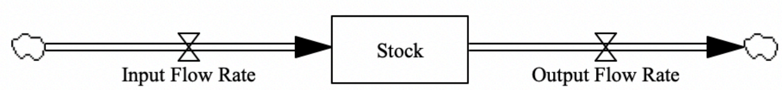
[195] Carley, "Computational Approaches to Sociological Theorizing," 1-2.

[196] Sokolowski and Banks, *Modeling and Simulation for Analyzing Global Events*, 57.

rate; it is the levels in a system, as well as exogenous influences, that determine the values of the rates.

Figure 5.1

Basic Stock and Flow Model



A simulation design most useful for predictive purposes for plastic marine debris would be one that shows how variations of different variables would affect the outcome of the system over set time periods. For the purposes of this paper, the simulation is framed for both an initial run without any further governance intervention on plastic marine debris accumulation and for a long-term run representing governance interventions over a 50-year period. There are, however, two distinct challenges with simulating this model. First, simulations are predicated on having relevant data that affords modelers the ability to establish numerical relationships among all the variables, unfortunately there is no complete data on plastic marine debris at this time. Second, even if such data were available, a common concern regarding data collection in the international arena is that states typically assemble data independently and provide it to a collective agency, so there is no assurance about consistency in data compilation.

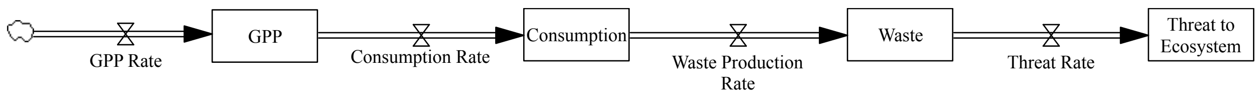
While this implies an accurate simulation of plastic marine debris is not possible, on the contrary, modeling and simulation are tools that help provide potential results. With this in mind, a simulation of plastic marine debris can be constructed for the purposes of demonstrating the possibilities of this model utilizing notional values that are estimates based on what is observed in the real world. Therefore, the following section will provide a simulation that demonstrates a projected response of stocks based on fluctuations in system variable values which could be further tested and validated with real-world data. This provides not only an understanding of how the system functions but offers a simulation that could aid in the development of mitigation strategies if relevant data becomes available.

Stock and Flow Setup

As with the CLD, the stock and flow development is accomplished in phases with several components. The first phase of transforming a CLD into a stock and flow is to design the primary components as indicated in Figure 5.1. This requires the linkage of all four stocks with flow rates in a manner consistent with the CLD and is provided in Figure 5.2. Acknowledging that sources feed the system from outside, a cloud starts the laydown and is then followed by a flow into the first stock which is GPP. The output of GPP flows into Consumption and similarly that output flows into Waste which then flows into Threat to Ecosystem. The flow rate leading into each stock is a regulator of that stock, thus each is labeled in such a manner: GPP Rate, Consumption Rate, Waste Production Rate and Threat Rate (respectively). This provides the base of the stock and flow.

Figure 5.2

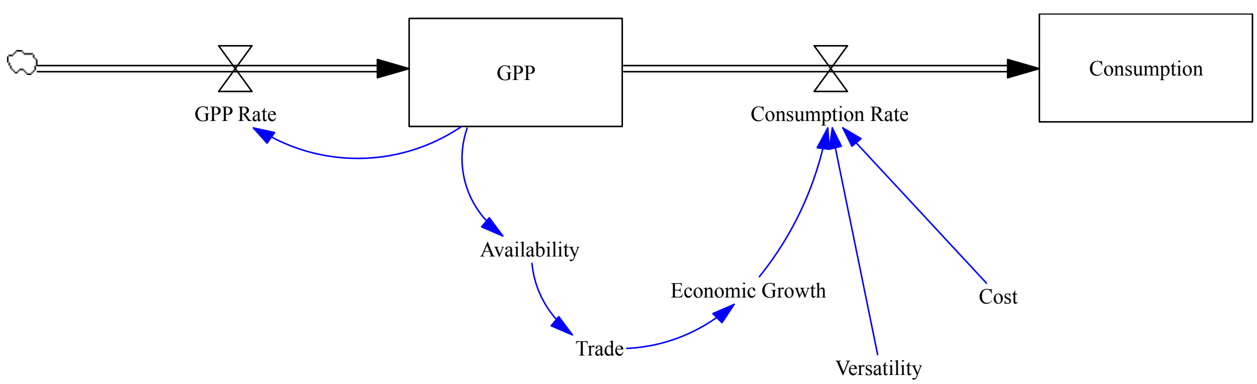
Base of Marine Debris Stock and Flow



In order to build out the rest of the stock and flow the same phased approach as that in the CLD is taken, though the two portions of Phase I are not broken out. Figure 5.3 represents this first phase where GPP generates Availability, Trade, and Economic Growth. Each of these, along with Versatility and Cost contributes to the Consumption through the Consumption Rate. GPP also contributes directly to the GPP Rate which is represented by an additional link.

Figure 5.3

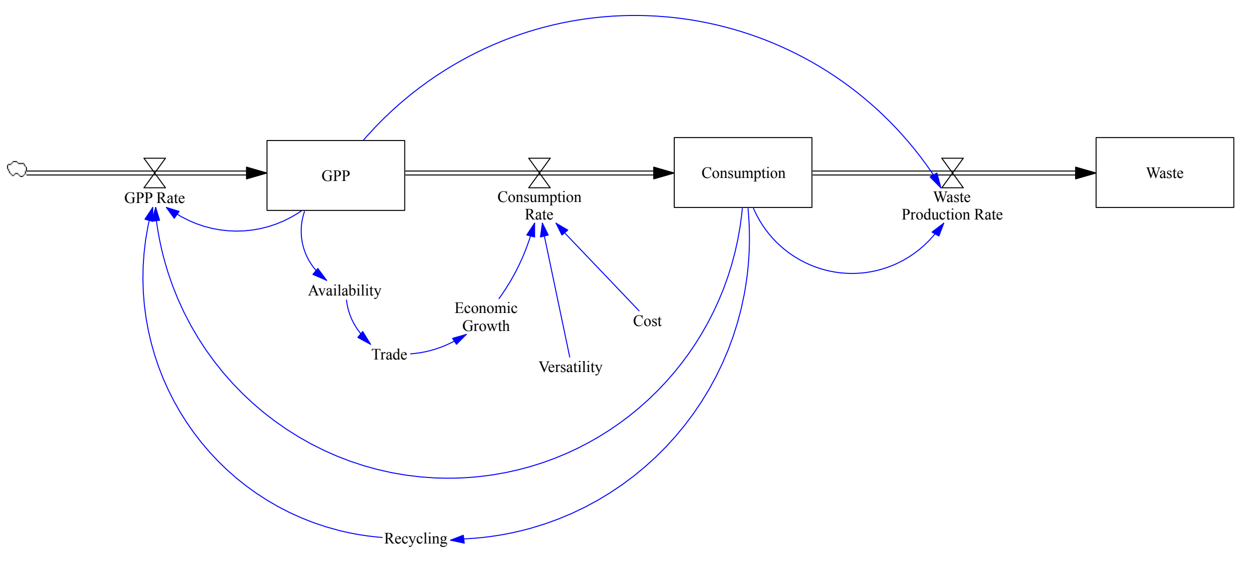
Phase I of Marine Debris Stock and Flow



The output of Consumption is accounted for in Phase II, depicted in Figure 5.4. As discussed previously in the CLD build, the majority of plastic post-consumption becomes Waste as a stock and is accounted for by the arrow from Consumption through Waste Production Rate. However, some plastic is fed back into GPP via the GPP Rate through Recycling. At the same time, an additional arrow is drawn from Consumption directly back to the GPP Rate in order to account for the direct impact Consumption has on GPP. Similarly, there is a portion of plastic that immediately becomes waste in the manufacturing process this is accounted for by the GPP to Waste Production Rate arrow.

Figure 5.4

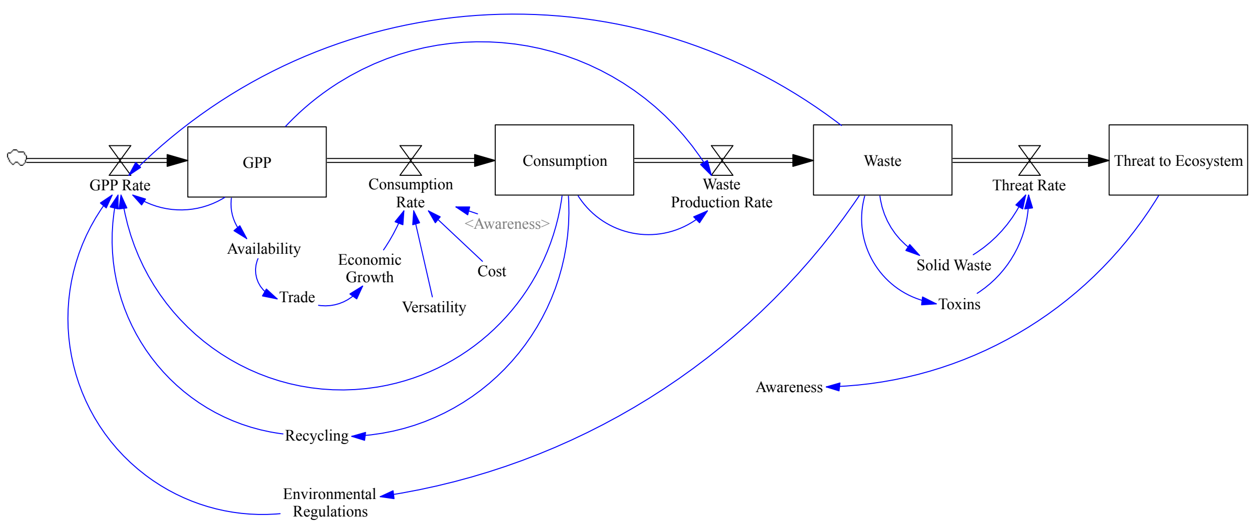
Phase II of Marine Debris Stock and Flow



The final phase of the initial build incorporates the stock Threat to Ecosystem as shown in Figure 5.5. Phase III first provides the link from the Waste stock to the Threat to Ecosystem through the Threat Rate via both the Solid Waste and Toxin variables. Waste also contributes to the GPP rate in the way it is managed by Environmental Regulations. Finally, Awareness is inserted, connecting back to Consumption through the Consumption Rate, and is represented by a shadow variable in order to avert arrow lines crossing. It is also connected back to GPP through Consumption's connections to the GPP Rate.

Figure 5.5

Phase III of Marine Debris Stock and Flow



Variable Associations and Assumptions

The application of a stock and flow diagram requires further consideration of each variable in order to determine appropriate units of measure.   It also requires a deeper exploration of the relationships between variables to ensure the units are properly associated. This results in a more comprehensive understanding of the system than the CLD alone.

As with the CLD, the starting point for the stock and flow will be the GPP stock since all outcomes of plastic originate with its production. This stock, along with all other variables, requires the assignment of a notional value that is relatable to other variables, and is chosen with consistency of scale as well as credibility in its relationship to real-world GPP. Fortunately, such data is available on a limited scale from Geyer, Jambeck and Law who calculated that 7,500 Mt of total plastic has been produced from origination in 1950 and is the basis for all numerical relationships developed henceforth.[197] Utilizing a notional scale of 0-10, the initial value of 5 is designated for GPP which represents the 7,500 Mt and is placed in the middle of the scale, allowing for both exponential growth and balancing over the two simulations (non-intervention and 50-year governance intervention).

The variables Availability, Trade, and Economic Growth are all outputs of GPP in the same loop within the CLD, therefore, they have a cumulative effect on Consumption. Assumptions are made regarding the role each of these variables has on GPP's connection with Consumption, with Availability designated as the initial driver. Since notional values are in use, it is estimated that 95% of GPP is made available in this process or 4.75 on the notional scale. The follow-on assumption is that 100% of Availability is traded either domestically or internationally and 100% of Trade contributes to Economic Growth. For the purposes of this model Versatility and Cost are considered constants and are both assigned the value of 75% based on the general assumption that both variables have a strong influence on the stock that is Consumption. The determination of Consumption's value is based on an assumption that

[197] Roland Geyer, Jenna R. Jambeck, and Kara Lavender Law, "Production, Use, and Fate of All Plastics Ever Made," *Science advances* 3, no. 7 (2017): 1.

almost all of GPP is consumed, however, a small allocation is made for plastic lost or turned into waste during the production process. As a result, it is determined that 96% of GPP, or 4.8 on the notional scale, is a reasonable value assignment.

Incorporating Phase II while attempting to maintain as much real-world accuracy as possible starts with the value for Recycling and is once again based on Geyer, Jambeck and Law's assessment which equates to 9% of plastic waste, however, in order to proportionately associate this with GPP, the determination for waste first has to be made. Their study established that "approximately 6,300 Mt of plastic waste has been generated"[198] which is 80% of all GPP. Calculating 9% of all plastic waste (567 Mt) and then extrapolating it to GPP equates to 7% of GPP that is recycled. Consequently 7%, or 0.35 on the notional scale, is the value assigned to Recycling.

Integration of Phase III requires clarification on the delineation of the two waste variables, Solid Waste and Toxins. Both of these variables equal 100% of Waste which is the primary focus of the numerical accountability in this portion of the stock and flow, however, additional real-world associations provide useful context for calibration of the model. The study from Zimmerman et al shows that of 34 common plastics, 74% contained chemicals that triggered at least one toxic outcome, yet this is acknowledged to be very a limited study in the scope of all plastics. Furthermore, it does not account for a timeframe at which point plastics begin to emit toxins and, more pointedly, it does not address toxin emissions in the ocean. Although toxins in the ocean result from the decomposition of plastic due to exposure to rain,

[198] Ibid.

sun, wave action and other environmental conditions, much of the original plastic remains in fragmented forms, thus the larger percentage of waste in the ocean is assumed to be in some plastic form – Solid Waste. Furthermore, while there is little to no understanding regarding the dispersion of plastic toxins throughout the marine water column, it has been previously established that plastic is omnipresent. Since it takes an indeterminate amount of time for plastics to emit toxins in the ocean and solid plastic waste still remains even during the breakdown process that produces toxins, for the purposes of this study the assumption is made that 83% of Waste is Solid Waste which equates to 66% of GPP or 3.3 on the notional scale. The remaining 17% of Waste is assigned to Toxins which equates to 14% of GPP or 0.70 on the notional scale.

Although the establishment of environmental regulations has seen an increase in recent years, they are still disturbingly few in the aggregate. Most are associated with bans on select products with plastic bags the most notable, yet targeting individual products, often at only the sub-national level, is less than optimal. While useful in their attempts to address the problem, such bans only affect a tiny portion of the outcome while comprehensive regulatory measures remain severely lacking. Based on this understanding, the assumption is made that of all GPP only approximately 5% of it is regulated with environmental outcomes throughout the Phase III loop. Therefore, 5% is assigned to Environmental Regulations or 0.25 on the notional scale. As previously mentioned, 6,300 Mt of plastic waste have been produced which equates to 80% or a 4 on the notional scale, providing the value for the Waste stock.

Proceeding to the Threat to Ecosystem stock, the determination for an appropriate value is based on a separate study by many of the same authors that estimated up to 4.8% of plastic waste entered the ocean in 2010.[199] Rounding this number to 5% for simplicity provides the basis for Threat to Ecosystem and when converting it to a GPP relationship Threat to Ecosystem becomes 4% or 0.20 on the notional scale.

The final variable is Awareness of the threat that plastic creates in the marine ecosystem. Geyer, Jambeck and Law's study claims that since its origin in 1950 to 2015, half of GPP has been produced in the past 13 years indicating a rapid rate of increase. This, coupled with other indicators such as little to no waste management in many countries resulting in massive plastic river pollution into the ocean, as noted in chapter 2, as well as the very low global recycling rate and fragmentary governance approaches to the problem, suggests a very low Awareness value. Based on these indicators an assumption is made that approximately only 10% of the population have an Awareness of the Threat to Ecosystem and the greater GPP waste problem. This equates to 0.5 on the notional scale.

While the four stocks and ten auxiliary variables have been assigned notional values due to the lack of real-world data, the values are based on assumptions grounded by the limited real-world data that does exist. This has provided a modest calibration of the model for accuracy during the simulation process. The values have been compiled for expediency in Table 5.1 where the notional value is based on its relationship to GPP as are the percentages. These values are used in the forthcoming equations except in the case where they are annotated by an *; in these cases the percentage has been extrapolated from GPP to Waste and the percentage of Waste is used.

[199] Jambeck et al., "Plastic Waste Inputs from Land into the Ocean," 768.

Table 5.1

Variable Notional Values and Percentages of GPP

Variable	Notional Value	% of GPP
GPP [Stock]	5	N/A
Consumption [Stock]	4.8	96
Waste [Stock]	4	80
Threat to Ecosystem [Stock]	0.2	4 [5% of Waste]
Availability	4.75	95
Trade		[100% of Availability]
Economic Growth		[100% of Trade]
Versatility	3.75	75
Cost	3.75	75
Recycling	0.35	7 [9% of Waste]
Environmental Regulations	0.25	5
Solid Waste	3.3	66 [83% of Waste] *
Toxins	0.7	14 [17% of Waste] *
Awareness	0.5	10

* The simulation percentages used for these variables are those associated with Waste not GPP

Simulation Equations

The primary distinction between a CLD model and a stock and flow simulation model is that the simulation is a computational analysis of the theoretical model. Utilizing the notional values assigned to variables, based on noted assumptions, the interaction among variables can be observed in the simulation model through the application of mathematical equations. Each of the equations utilized in the simulation of this wicked problem is briefly described in the following paragraphs.

Following the same phased approach previously used in this project, the formulation of equations begins with Phase I, yet it becomes slightly more involved as the equations build. As such, components of a phase often have several factors that may draw from other phases, therefore, the simulation equations will follow in a slight variation from the laydown previously described. Additionally, the simulation will be based on a run that accounts for a period of 50 years, or 600 months.

Beginning with the GPP stock, a notional value of 5 is assigned and from that point forward is represented by the integral of the flow into the stock minus the flow out of the stock or $\int_0^{600} GPP\ Rate - Consumption\ Rate$ with these rates to be defined in the following paragraphs. The first three variables follow with Availability mathematically annotated as $(0.95 * \ GPP)$. Trade is then annotated as $(1 * Availability)$ and similarly Economic Growth as $(1 * Trade)$. Since Versatility and Cost are constants and have both been notionally assigned 3.75 or 75 % of GPP, they are both mathematically represented as (0.75). These values are applied to the simulation through the Consumption Rate as (Economic Growth * Versatility/ (Cost + Awareness)) shown in Equation 5.1. Please note that Awareness is a factor in this equation, yet Awareness is not defined until the final portion of the mathematical development. Similarly, the GPP Rate is not yet defined. As the mathematical equations continue to be designed, missing portions will be completed, and all factors represented in the simulation equations will be justified.

Equation 5.1

Consumption Rate Equation

$$Consumption\ Rate\ Equation = \frac{(1(0.95 * 5))(0.75)}{(0.75 + Awareness)}$$

In Phase II, Recycling is annotated as $(Consumption * 0.07)$ and the Consumption stock, like the GPP stock, has an initial notional value of 4.8. It is represented as $\int_0^{600} Consumption\ Rate - Waste\ Production\ Rate$ with the Waste Production Rate shown in Equation 5.2. The mathematical association with the Waste stock is moved to the next phase.

Equation 5.2

Waste Production Rate

$$Waste\ Production\ Rate = ((Consumption * 0.96) + (GPP * 0.05))$$

Phase III reaches back to define the Waste stock which has a notional value of 4 and, like GPP and Consumption is a product of the preceding rate minus the following rate or $\int_0^{600} Waste\ Production\ Rate - Threat\ Rate$. The two waste variables are defined next with Solid Waste represented as $(Waste * 0.83)$ and Toxins as $(Waste * 0.17)$. The Threat Rate is comprised of these two variables $(Solid\ Waste\ x\ Toxins)$ as shown in Equation 5.3 and leads to the final stock of Threat to Ecosystem with a notional value of 0.15 - annotated simply as the outcome of the Threat Rate.

Equation 5.3

Threat Rate

$$Threat\ Rate = \ (Waste\ x\ 0.83)(Waste\ x\ 0.17)$$

This in turns leads back to the missing variable representation from the first phase which is Awareness and is represented as $(Threat\ to\ Ecosystem * 0.1)$ and provides the final component to the Consumption Rate in Equation 5.1 which is now defined in Equation 5.4.

Equation 5.4

Consumption Rate with Awareness Defined

$$Consumption\ Rate = \frac{(1(0.95 * 5))(0.75)}{(0.75 + (Threat\ to\ Ecosystem * 0.1))}$$

The final variable, Environmental Regulations, is defined as $(Waste * 0.05)$ and is connected from Waste into GPP Rate providing the generation of the GPP Rate, shown in Equation 5.5 as *(Consumption+Waste-((Environmental Regulations*Recycling)+GPP))/((Environmental Regulations*Recycling)+GPP).*

Equation 5.5

GPP Rate

$$GPP\ Rate = \frac{(Consumption + Waste - ((Waste * 0.05)(Consumption * 0.07)) + GPP}{((Waste * 0.05)(Consumption * 0.07)) + GPP)}$$

Now that the mathematical equations have been defined, the simulation can be run, however, in order to represent the real-world as accurately as possible a function of time delay must be incorporated. This delay, or Adjustment Time as termed by Sterman in his book *Business Dynamics, Systems Thinking and Modeling for a Complex World,* is the "discrepancy between the desired and actual state of the system."[200] In other words, it represents the time it takes for the system to correct for a time delay due to the fact that some actions do not occur instantaneously.

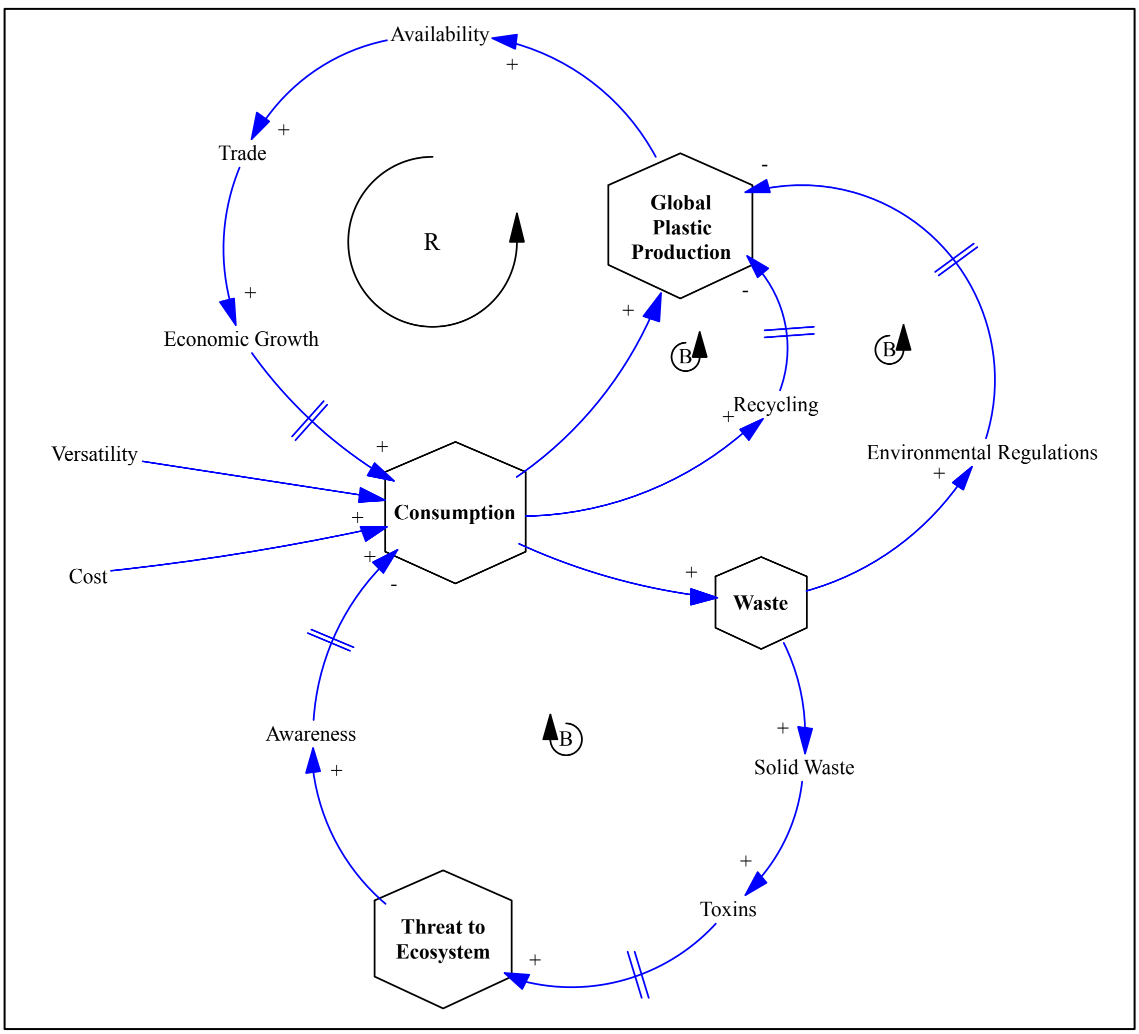
Applying an accurate representation of the incorporation of "delay" into this system dynamics model requires a referral to the CLD in Figure 4.7 for appropriate adjustments with CLD delays applied accordingly to: Economic Growth since this does not occur instantaneously but builds or declines over a period of time; Recycling because increases or decreases to infrastructure and capability for processing plastic waste happens incrementally; Toxins are generally discharged from plastic in a gradual manner but are sometimes released quicker than others; Environmental Regulations which take time to develop and implement; and Awareness

[200] Sterman, *Business Dynamics: Systems Thinking and Modeling for a Complex World*, 276.

which often grows slowly amongst the population. Of note, there is also a delay applied to the Waste Production Rate since some plastic (e.g.: construction, consumer electronics, and automobiles) becomes plastic waste at a much slower rate than the majority, particularly single use plastic. Each of these accounts for delays in different sections of the CLD where "delay" is represented by a double-hash mark (\\) thus refining the CLD as shown in Figure 5.6.

Figure 5.6

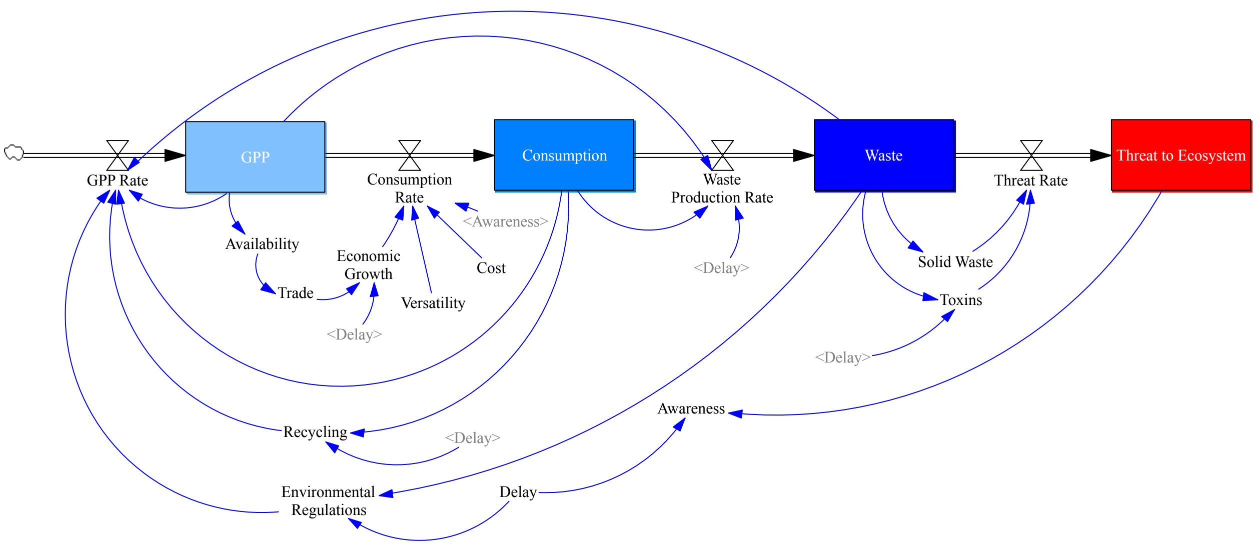
Marine Debris Causal Loop Diagram with Delay



This, in turn, requires the modifications to the Stock and Flow simulation of Figure 5.5 which, when applied, results in Figure 5.7. In this figure, the delay function is connected as a separate variable that links to each of the five variables mentioned above but there is also a delay that must be factored into the Waste Production Rate. Several of these connections are represented by a shadow variable as was Awareness in Figure 5.5.

Figure 5.7

Marine Debris Stock and Flow with Delay



At each point where delay occurs, a modification is required to the previous equations as noted below:

Economic Growth = *(1*Trade)/Delay*

Recycling = *(Consumption*0.07)/Delay*

Toxins = *(Waste*0.17)/Delay*

Environmental Regulations = $(Waste * 0.05)/Delay$

Awareness = $(Threat\ to\ Ecosystem * 0.1)/Delay$

Additionally, the Waste Production Rate incorporates delay as shown in Equation 5.6 and in turn replaces Equation 5.2.

Equation 5.6

Waste Production Rate with Delay

$$\frac{((Consumption * 0.96) + (GPP * 0.05))}{Delay}$$

Simulation Products/Outcomes

Following design completion, the simulation model is run and observed for outcomes associated with the 50-year period, represented in months (600) for practicality. However, prior to running the simulation a determination was made that in order to represent the intervention of governance, a first run would be made according to the initial setup and a second run would increase three variables - Recycling, Environmental Regulations and Awareness - by a factor of seven indicating governance intervention. The variables chosen were done so because they are logically impacted by governance. The corresponding equations for these changes are seen in Equations 5.7 – 5.9 below.

Equation 5.7

Recycling with Governance Intervention by a Factor of 7

$$Recycling = (Consumption * 0.07/7)/Delay$$

Equation 5.8

Environmental Regulations with Governance Intervention by a Factor of 7

$$Environmental\ Regulations = (Waste * 0.05/7)/Delay$$

Equation 5.9

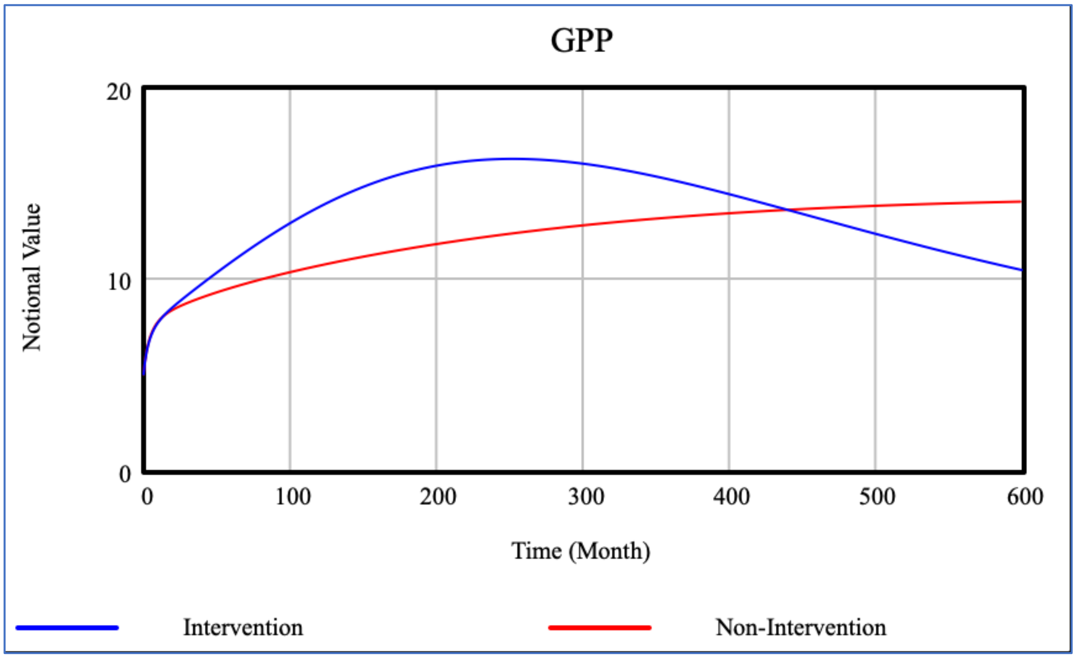
Awareness with Governance Intervention by a Factor of 7

$$Awareness = (Threat\ to\ Ecosystem * 0.1 * 7)/Delay$$

Starting with the results of the GPP stock, as shown in Figure 5.8, exponential growth is initially apparent for both the non-intervention and intervention runs with the non-intervention run demonstrating a goal-seeking curve as the rate of change diminishes. Meanwhile, the intervention run appears to have a more pronounced growth, yet as the intervention measures surpass the delay and noticeably impact the system a balancing effect occurs and drives the demand for GPP down. This is further apparent when reviewing the month-by-month change (located within the modeling tables in Appendix) which shows that the intervention numbers increase more slowly around the 25-30-month period which means that the rate of change is slowing. If only viewing the graph, it appears that the change only occurs after the 200th month period, but the details which models such as this can provide via additional tools available in the modeling program, such as incremental tables that show the mathematical development month-by-month but for the purposes of this paper they are omitted due to their excessive volume (but can be viewed in the Appendix), help provide a deeper understanding of the model's performance. In this case, governance intervention has a noticeable balancing effect on GPP which begins after only a few years and then becomes more pronounced as more time passes. Eventually, the growth rate ceases at the 284th month and then begins a more pronounced balancing effect through the representation of a decline in growth.

Figure 5.8

Simulation Results for GPP Stock

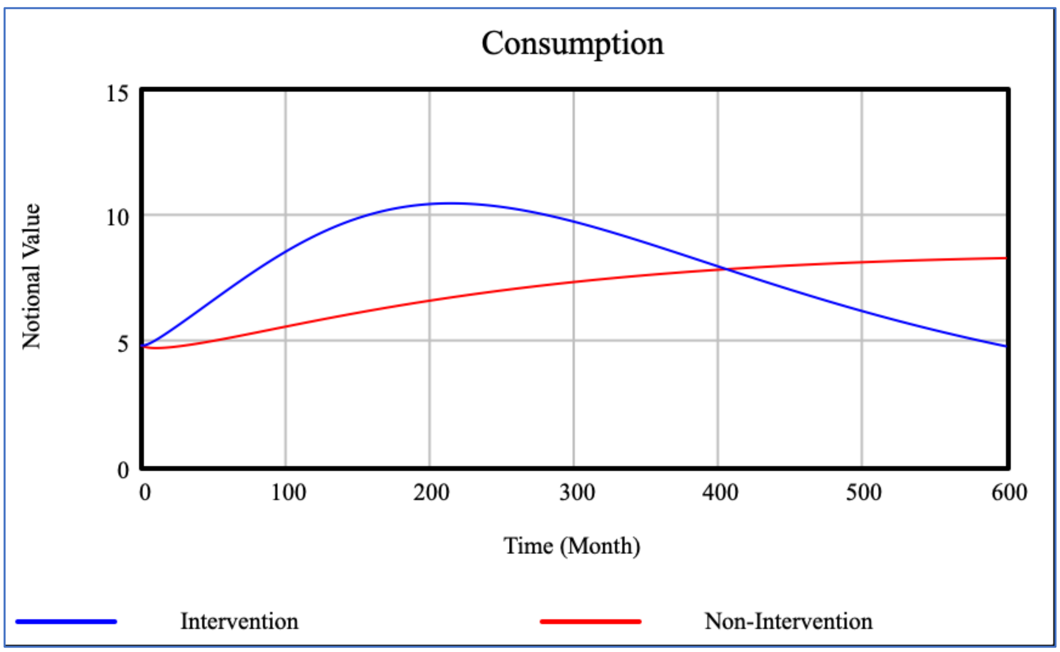


The model was then run for a period of 1200 months (100 years) to view the continued decline of growth associated with governance intervention, however, at 1200 months, growth was 5.44 which remained well above the original notional value of 5.

When reviewing the Consumption stock, shown in Figure 5.9, a similar response is observed with both non-intervention and intervention. The non-intervention growth continues at a relatively consistent yet slower rate while the termination of growth associated with the intervention run occurs sooner than that associated with GPP, roughly at the 200th month point, and is more pronounced. This is indicated in both the graph and the incremental tables, which supports the CLD and stock and flow model designs' assumption that Consumption represents a driving factor of GPP. As with the GPP model, the Consumption model was also run for a 1200-month period which shows the growth declined to 1.8. This significant decline demonstrates an impressive balancing achievement created by governance action.

Figure 5.9

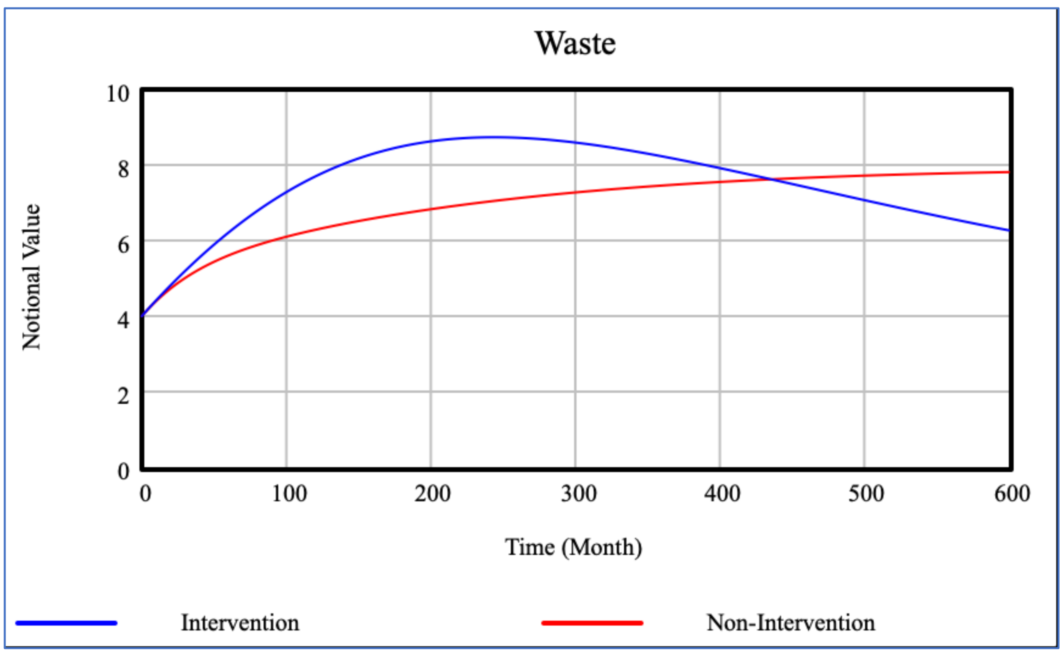
Simulation Results for Consumption Stock



Turning to the Waste stock, represented in Figure 5.10, a similar pattern is seen with the non-intervention growth curve demonstrating a steady increase in plastic waste. When the simulation surpasses the delay, a slowing rate of growth is noticeable on the chart and is also noticeable in the incremental tables for the intervention of governance. The intervention also shows a peak of plastic waste production at the 263rd month followed by a steady decline. The incremental tables associated with a 1200-month run show the decline reaches 3.8 which is lower than the starting value of 4 and indicates the potential for an improvement over current values of plastic waste. This can be assumed as a direct result of the decline in Consumption and GPP.

Figure 5.10

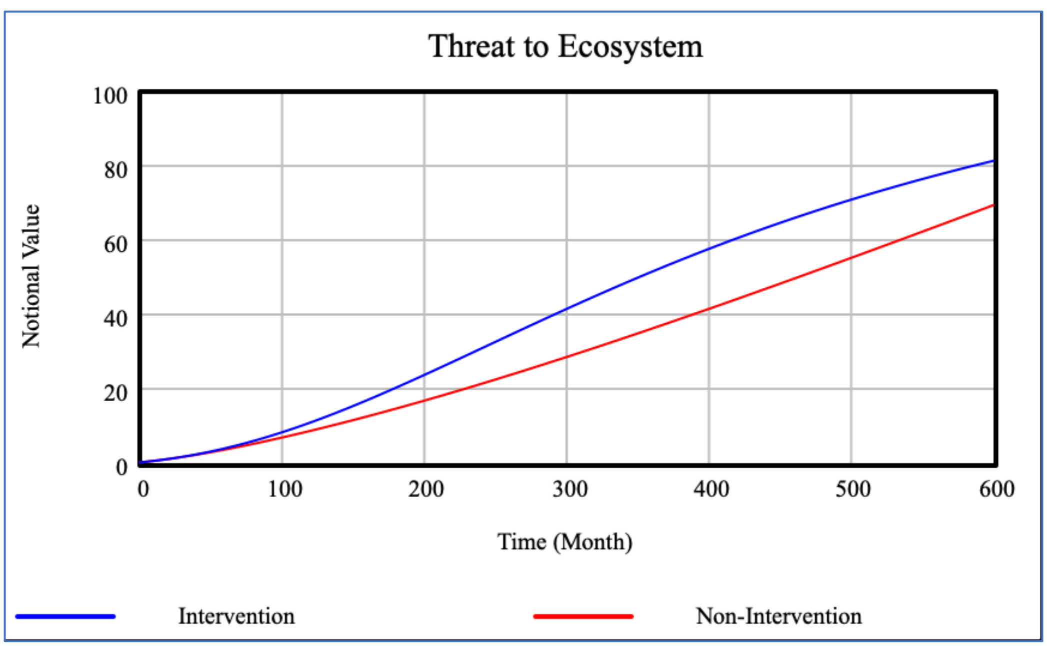
Simulation Results for Waste Stock



Finally, a review of the Threat to Ecosystem stock, the principal dependent variable in the system (Figure 5.11) shows a disturbing trend of growth in both situations. When each of the data elements in the incremental tables are observed for governance intervention a slowing rate of growth is noted around the 24-month period, however, shortly thereafter it does increase again slightly until about the 400th month where a decline is once again evident. The rate of growth continues to slow more obviously as it approaches the 500th month and, while there may be a perception that a representation from the previous stocks would show the intervention curve in the Threat to Ecosystem to decline below the non-intervention curve, in fact the intervention growth rate has slowed more than the non-intervention growth rate by the 600th month. Furthermore, the intervention rate continues to slow consistently through the 1200th month period.

Figure 5.11

Simulation Results for Threat to Ecosystem Stock



The point of applying this model to a wicked problem is not to look for a curve that necessarily shows a dramatic decline, but instead to look for a simulation that produces a slowing of the growth rate of the Threat to Ecosystem, as this model does. The Threat to Ecosystem should cease to grow at an exponential rate when governance starts to take effect ostensibly because the flow of marine plastic debris into the ocean declines. However, there is no variable that actually drives a decrease in the debris. Such an outcome is acceptable and anticipated though, because in actuality, what is in the ocean will remain (for the most part) due to fragmentation and dispersion throughout the water column unless a future mechanism is designed to safely remove plastic from the marine environment. In an attempt to replicate current real-world variables, this simulation demonstrates that governance actions will predominantly affect only the input of plastics into the ocean. This reinforces the argument that it is a wicked problem, where something can be done about the increase, but there won't necessarily be a decline in the Threat Rate. While this simulation is not a predictor of actual behavior, it does provide a notional response of the system based on the assumptions made about the behavior of the system and the relative effects of the variables involved. As real-world data becomes available, the model can be refined to improve its accuracy and thus more closely represent the true behavior of the system.

Conclusion

Framing system dynamics in a two-step process offers a CLD that represents the conception and design of the model while demonstrating the function of a system. The CLD is useful for communicating high-level views of the plastic marine debris system. Developing a

CLD for this problem produces an easily understandable visual device which provides a sound first step for the systemic analysis of this problem. The stock and flow diagram then provides a second opportunity to analyze the model because it represents the temporal behavior of the system in mathematical terms and depicts how the system would respond given the assumptions made about what affects the system.

The conception and simulation of the plastic marine debris issue as a wicked problem used estimated sample parameters, associated as closely to real-world data as possible, and is based upon various assumptions previously provided. All variables, whether stocks or auxiliary variables, influence the dependent variable - Threat to Ecosystem - even if only indirectly. The stocks of GPP, Consumption and Waste indirectly impact the dependent variable on different levels and through different links as noted by both the CLD and the stock and flow diagrams. Ultimately, however, they are all tied to Threat to Ecosystem because it is a contained and connected system.

The simulation has shown that with the introduction of a minor governance measures, noticeable changes that represent a decline in the production and consumption of plastic, as well as waste generated, are possible. It presents a compelling argument for further exploration of such non-traditional ways of considering governance of issues in the global commons. Furthermore, the plastic Threat to Ecosystem within the marine environment is not only based on the many millions of tons of plastic discharged to the system each year but is also compounded by existing threats from plastic residing in the ocean since the 1950s. Therefore, if the flow of plastic into the ocean, the growth rate, is slowed then progress on this wicked problem is possible.

CHAPTER VI

THE CHALLENGES OF MARINE DEBRIS: DRIVING A NEW FRAMEWORK FOR GOVERNANCE - DISCUSSION AND CONCLUSIONS

"It is the predicament of [humankind] that man can perceive the problematique, yet, despite [our] considerable knowledge and skills, [we do] not understand the origins, significance, and interrelationships of its many components and thus [are] unable to devise effective responses. This failure occurs in large part because we continue to examine single items in the problematique without understanding that the whole is more than the sum of its parts, that change in one element means change in the others."[201]

- William Watts, President, Potomac Associates in the Forward of "The Limits to Growth"

"A sustained educational effort is needed to change attitudes toward oceans, to see them as central to our world, not peripheral; and as a way of seeing the world anew, not simply as a final resource base to maintain for a few more decades a tired and diminishing industrial, postcolonial age."[202]

- Jeremy Plant from a review of "The Future of the Oceans: A Report to the Club of Rome"

Introduction

The previous chapters provided an understanding of the complexity of a wicked problem. Also provided was a heuristic method for conceptualizing the wicked problem of marine debris through the depiction of a system dynamics casual loop diagram and a simulation that represents the temporal behavior of the system and how it would respond given the assumptions made about what affects the system. In contrast, tame problems are

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[201] Donella H. Meadows et al., *The Limits to Growth: A Report to the Club of Rome's Project on the Predicament of Mankind* (New York: Universe Books, 1972), 11.

[202] Jeremy F. Plant, "The Future of the Oceans: A Report to the Club of Rome (Book Review)," *Environmental Review: ER* 11, no. 2 (1987): 160-61.

characterized by familiar structure and identifiable solutions that most individuals, scholars, corporate leaders, heads-of-state and institutions routinely encounter. This chapter contends that the framework of current governance to address marine debris is lacking and that the model implies a paradigm shift is necessary for communities and policymakers alike. Under this new paradigm, leaders must focus on a progress-oriented approach instead of the current solution-centered paradigm that requires reframing governance and its associated norms.

Under normal circumstances, a system dynamics model offers a framework for solving the tame problem to which it has been applied. It readily identifies a solution or, as Rittel and Weber stated, "…the problem-solver knows when he has done his job. There are criteria that tell when *the* or *a* solution has been found."[203] However, this requires data to complete the modeling steps that produce the solution. In the case of marine debris, a wicked problem by its very nature, the required data is not available to programmatically produce an "ultimate test of a solution."[204] Instead, the model is used in an atypical manner to explore challenges of a wicked problem through visual representation.

The lack of sufficient data for solving the problem does not negate the contribution of the model to facilitating the formulation of a means through which the problem can be confronted. Practitioners of international relations problem-solving inherently turn to governance for the majority of issues contemplated. However, as with wicked problems, governance is complicated and manifests in various forms. This poses a unique situation:

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[203] Rittel and Webber, "Dilemmas in a General Theory of Planning," 162.

[204] Ibid., 163.

wicked problems fundamentally defy governance, yet it is precisely those type of problems that need governance.

A review of the dependent variable, *Threat to Ecosystem*, will address not only status of the threat, and predictions for the future, it will also assess social and state behavioral aspects that impact governance opportunities for success. The analysis and implications of the model will then provide a deeper understanding of the complexity, challenges and opportunities associated with marine plastics. Restructuring those behaviors and associated norms in order to establish a new framework for governance offers optimism for progress on this and other global commons wicked problems, and is discussed more in-depth later in the chapter. While there is no "quick and easy fix," there are opportunities to achieve significant progress through governance, progress which is not only necessary but urgent.

The Increasing Threat Posed by Marine Plastic Debris

While solely an anthropogenic marker, only existing as a consumable product for the past 70 years, plastic's mass production and ubiquitous consumption have created the tremendous waste that has made its way at an uncontrolled rate into the marine environment, an environment critical to not only humans but to all life on earth. This has created a "global plastics crisis [which] presents a 'wicked' multiplicity of challenges, among them plastic's ubiquity, its persistence in nature, and the cross-boundary effects of plastic pollution."[205] The staggering volume of plastics continuously entering the ocean further exacerbates the already

[205] Tobias D. Nielsen et al., "Politics and the Plastic Crisis: A Review Throughout the Plastic Life Cycle," *Wiley interdisciplinary reviews. Energy and environment* 9, no. 1 (2019): 2.

immense stress placed on the ocean by other factors such as ocean acidification, climate change, overfishing, and decades of agricultural and industrial pollution. The complexity of the marine debris system makes each factor of the threat multiplicative rather than additive in its effects on the others. The system does not simply represent several individual variables creating distinct problems but represents a compounding set of problems that amplify the seriousness of the threat.

Pervasive marine plastic also distributes the threat across multiple-parallel fronts illustrated by means of four spheres: environmental, humanitarian, economic and political. Most obvious is the environmental sphere which refers to the natural world and the ecological effects on its condition. The marine environmental influences of human activity associated with plastic debris are extensive and impact every organism in the ocean due to the material's omnipresence throughout the water column, from garbage patches on the surface all the way to the seafloor's greatest depths, in ice-core samples as well as in melting water from sea ice, and in the prevalence of shoreline/coastal litter. The persistence of plastics in the ocean contributes to the decline in the health of fish-stocks and marine fowl, the degradation of coastal and mangrove habitats, and ultimately to the loss of marine biodiversity.

Humanitarian elements of this problem range from filthy, toxic rivers and coastal waters which have multiplicative impacts on coastal populations, to food security trepidations regarding both solid plastic particles and toxic "bio-accumulation (within one individual) and bio-magnification (along the food chain),"[206] to the spread of pathogens that affix to floating

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[206] Kate O'Neill, *The Environment and International Relations*, 2nd ed. (Cambridge: Cambridge University Press, 2017), 35.

plastic and are globally circulated via ocean currents. The unconstrained flow of plastics into the ocean compounds these concerns not by the year or day, but by the minute and even second.

The global economy is also threatened. Poisonous infiltration and/or entanglement of fish-stocks destroys livelihoods particularly in coastal regions where populations depend heavily upon fishing and other aquaculture. Follow-on effects throughout the supply chain harm the global seafood industry. Fouled maritime equipment such as commercial fishing gear and damaged transport vessels delay or even terminate business endeavors. Recreational activities lose their appeal due to the plastic that mars an environment prized for its beauty. Communities are deprived of tourism revenue and must also pay for clean-up, particularly in the coastal area where recreational activities are most prevalent. Ocean-derived human benefits are estimated to have declined approximately 5% as a result of plastic pollution, equating to as much as $2.5 trillion a year.[207]

Plastic marine debris also poses a political threat. Whether it be NGO collaboration with IGOs and their member states epitomized by the Ellen MacArthur Foundation and World Economic Forum's work on a new plastic economy, the collective efforts of the European Union's Plastic Strategy, or individual state and local regulatory measures on plastic bags or other single-use plastics, it is impossible to separate this wicked problem from politics due to the existential threat it poses. The politics of production are linked closely with domestic economics, waste management including international trade in plastic waste, or regulatory

[207] Nicola J. Beaumont et al., "Global Ecological, Social and Economic Impacts of Marine Plastic," *Marine pollution bulletin* 142 (2019): 193.

efforts to restrict consumption of single-use plastics. The damage to the marine environment from plastics underscores "the lack of effective policy responses."[208]

Plastic marine debris is an international issue whose complexity is evidenced by "the diversity and abundance of sources, the persistent nature of most plastics and other garbage, and the ability of tides and currents to carry debris long distances."[209] Because it continues to grow exponentially, without concerted collaborative work, marine debris will ultimately reach a point of no return and threaten the entire planet – as discussed in previous chapters, recent scholarship indicates this is more imminent than previously believed. Although a daunting task, urgent action is needed.

Analysis and Implications

Although marine debris is recognized in the generic context - plastics that continue to enter the ocean at an alarming rate without compensatory extractions - the perception of this threat demands further exploration to adequately elevate its veracity and galvanize urgent action. Additional analysis of the model constructed in Chapter 4 and simulated in Chapter 5 offers insight into a system composed of numerous variables that impact each other in myriad ways, and highlights the complexity of this dynamic system that brands it as wicked and demonstrates the inherent threat it poses.

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[208] Nielsen et al., "Politics and the Plastic Crisis: A Review Throughout the Plastic Life Cycle," 6.

[209] National Research Council, *Tackling Marine Debris in the 21st Century*, 17.

Ontological arguments supporting wicked problems contend that such problems are not "solvable" in the traditional sense of the word. The complexity of their dynamic relationship demonstrates that the manipulation of a variable is not limited to a linear cause and effect outcome. Instead, when one variable is altered, due to the interconnectivity of a dynamic system, the entire system is affected. This is a crucial point for understanding the implications of this model and simulation because it helps reframe the customary manner by which problems are addressed: It acknowledges that the system is both complex and dynamic, and needs to be considered from a progress-oriented instead of a solution-centered mindset.

Utilizing a CLD (Figure 4.7) creates a visual definition of critical variables that influence how the marine plastic debris system behaves and displays their interconnectivity within the system. While not all connectivity is detailed through direct links in the CLD, by virtue of a closed system (one limited by the variables selected for this model), many variables indirectly influence each other. It also demonstrates the central characteristic of a dynamic system - feedback loops – which either reinforces (the *GPP* and *Consumption* loop shown in Figure 4.5) or balances (the additional loops created by *Recycling*, *Environmental Regulations* and *Awareness* shown in Figures 4.6 and 4.7) effects on the growth of the threat to the marine ecosystem.

The CLD depicts four distinct feedback loops. The first loop contains the genesis of all plastics problems (which is *Global Plastic Production*), several variables that stem from *GPP* (*Availability, Trade and Economic Growth*) and the demand for the product (*Consumption*), further driven by low *Costs* and high *Versatility* that create a significant reinforcing loop, one that will generate exponential growth of plastic. Two additional loops are expansions of that initial loop where one incorporates *Recycling* for a marginal balancing opportunity and the other incorporates *Waste*. By itself, *Waste* would compound the exponential growth; however, the incorporation of *Environmental Regulations* offers an opportunity for balancing. The final loop is composed of *Consumption*, *Waste*, *Solid Waste*, and *Toxins* which all ultimately impact the dependent variable – *Threat to Ecosystem*. One remaining variable (*Awareness*) provides the potential for balancing as do *Recycling* and *Environmental Regulations*. While each of the three balancing loops is small, and currently unable to overcome the volume of *GPP* and *Consumption* which creates *Waste* entering the ocean resulting in a rapidly increased *Threat to Ecosystem*, they do present a prospect for expansion of balancing mechanisms in the system.

While a CLD is an excellent tool to understand the dynamics of a system (through a visual representation), the translation to a stock and flow diagram, reflective of the actual functioning of the marine plastic debris system, provides the opportunity to simulate how modifications to the system will affect various outcomes. In order to enhance veracity of the model, calibration is required to compare the simulation model to the real-world system, and to incorporate necessary adjustments to the simulation so it replicates the behavior of the real-world situation it represents. This was done within the limits of the chosen variables utilizing derivations from what limited real-world data was available via an iterative process. The result is a calibrated model, at a minimum from a notional perspective.

This process provides the flexibility to simulate the system under a number of variations to the chosen variables. For example, the simulation has an established base run (non-intervention) over a period of 50 years (600 months). A variation by a factor of seven is then made to *Awareness*, *Recycling* and *Environmental Regulations* and the growth rate of the four stocks noticeably declines. While this alone is promising for addressing marine plastic debris, further changes could be made to expand the understanding of effects on the system and various "what if" situations. Instead of adjusting *Awareness* by a factor of seven, the simulation could be run to determine the systems change if *Awareness* was only adjusted by a factor of two while both *Recycling* and *Environmental Regulations* remain set at the base run numbers. Similarly, if *Awareness* was not adjusted but either *Recycling* or *Environmental Regulations* were, the impact of those changes could be observed. In fact, any combination of the variables could be adjusted to provide extensive insight into the potential reinforcing or balancing effect each variable exerts within the system.

While the graphs provided in Chapter 5 illustrate the eventual balancing effect an adjustment to *Awareness*, *Recycling* and *Environmental Regulations* can have on the system, an initial assessment might lead one to believe Intervention actually increases the growth rate and exacerbates the *Threat to Ecosystem*. However, proper analysis requires that the system be viewed holistically; it cannot be viewed through a lens of isolated parts. As the name implies, the system is dynamic and that is key; all variables have an effect on one another. For example: A affects B and simultaneously B affects A. This feedback portion of the system grows increasingly complex based on the number of variables and their associations within the system. This is not obvious from a visual standpoint until the balancing consequences of those interactions appear over a period of time, highlighting the point that changes in a dynamic system like this will be best observed in the long-term. Analyzing the system outcomes solely through the interpretation of its graphs is insufficient to capture its true dynamic character.

Analysis of the imbedded tables allows for deeper insight. They reveal a notable decline in the growth rate not visible on the graphs, yet observing what happens in the tables at each time interval does not present a true understanding of the dynamic relationship either. What does offer that correct comprehension is the overall behavior of the model as all of the variables have a chance to interact with each other over time. Variations in the stock values are observable as the system progresses because of that dynamic interaction, and whenever a parameter in that system is changed, how that interaction occurs is going to change as well. For example, changes that increased the *Recycling* variable have numerous other impacts beyond the limitations of this model; however, it is easily understood that there are funding demands to ensure increased and suitable collection tools, and trained personnel and facilities are in place to manage the intake. Steps are necessary to ensure proper supply lines are in place to forward the recycled and processed material to the new production line. Both the public and commercial population must be suitably notified and educated to sufficiently prepare for the changes and requirements for disposal at collection sites. These factors of *Recycling* have a tangible link to each variable in the system, highlighting their dynamic interaction and the overall complexity of the system while also emphasizing the need to view the system holistically instead of from a linear cause and effect perspective. Furthermore, this also elucidates the incorporation of time delay within the system. Delays must be taken into account because an intervention's impact is not instantaneous but occurs over time.

Interestingly, while manipulation of the chosen variables showed notable declines in the *GPP*, *Consumption* and *Waste* stocks while also showing a notable slowing of growth in *Threat to Ecosystem*, these changes were not fully rectifying the problem associated with each stock.

For example, the *GPP* stock simulation revealed a decline, or balancing effect at both the 600-month and 1200-month periods; however, even at 1200 months the notational value was 5.44 which was still above the original of 5. This further confirms that wicked problems are not easily solvable and demonstrates how incremental improvements can significantly retard the growth of the threat.

This project observes the interaction of variables during a particular timeframe and provides policymakers, scientists, engineers, corporations and individuals with a deeper understanding of how the system reacts to variations. This insight helps direct energy and resources to operationalize the theoretical concept through manipulation of those variables most likely to realize progress on curtailing the exponential growth of this wicked problem. The results of the system design and simulation support this intuitive conclusion through the holistic concept of understanding the characteristics of dynamic systems.

Additional implications offer a contribution to existing scholarly work. Conceivably, if local, national or global government had taken earlier and more significant action regarding plastics, the model implies that reductions of growth would have been detected at an earlier stage in the system. Given their inherent consumer power, had local communities not accepted the proliferation of plastic packaging, demands for alternatives could have been made decades ago. While some states have imposed bans on plastic bags and other single-use plastic items in recent years, the growth in plastic waste has been long observed, but actions to mitigate it have not been developed in parallel. This is evidenced by the US which still does not have national regulatory measures on plastic bags or single-use items. Had such measures been instituted in the late 1990s or early 2000s, reductions in the plastic growth rate would have been realized in a manner that facilitated a larger and more immediate balancing action. Ostensibly, this would have modified or established new norms that drove home the point of the necessity of behavioral changes. Earlier reduction is more advantageous to the health of the system and therefore renders it less wicked. Similarly, if IIs had more robust ability to both institute and enforce rules and create and change norms, the model implies the balancing effects to marine debris would be more notable which is translatable to other wicked and global common problems. Moreover, at a local level, better-informed communities would be incentivized to recycle on a larger scale which markedly increases a balancing effect in the system.

Regardless of the expanded application of its utility, the model demonstrates the wickedness of marine plastic debris through the multitude of cause and effect actions of the variables' dynamic interactions, and emphasizes the system's complexity - an inherent characteristic of wicked problems. While other similar problems exist (e.g., Climate Change), marine plastic debris is unique because of its relatively unrestricted growth. It increases the threat to the marine ecosystem with the production of toxins as well as compounds other ocean challenges such as threats to transportation and to the food chain. No mechanism exists to eradicate the plastic that is spread throughout the ocean's water column and seabed. Therefore, the threat it poses is far greater than current action to counter it. What remains to be determined is how useful this concept and model are in a governance approach. This project asserts that the application of various "what if" situations to the theoretical model produces empirical data and will lead to appropriate policies that foster progress.

Governance and Norms: A New Paradigm for Tackling Marine Debris and Other Wicked Problems

Tackling wicked problems is extremely difficult, but just because it is complex and poses tremendous challenges neither suggests the problem is impossible to address nor implies it be overlooked in order to focus on problems easier to define or that have more obvious solutions. Overly complex, indeed wicked, problems are often ignored because they are difficult with no obvious solution. Yet, when considering marine debris, that is not an option - it is both necessary and urgent to address this wicked problem owing to the existential threat it poses.

In order to properly address such a problem, actors must reframe the way they think. If they are willing to reconceptualize the way a problem is understood instead of defaulting to linear thinking that places severe constraints on knowledge, actors may create increased opportunities to grasp the intricacies of the problem precisely because they are not bounded by traditional limitations. This naturally creates a more open disposition to then assess the problem through a new lens, one where a system dynamics model can facilitate a more thorough understanding of a complex problem.

The system cannot be properly assessed without considering governance and the norms that support it. However, this project would be blinded by hubris if it were to profess an all-encompassing assessment of governance and norms were to be applied within its limitations. Therefore, an abbreviated discussion of the importance of governance and norms follows, emphasizing the need to modify existing norms to explore a more encompassing and collaborative governance on all levels.

In the international relations sphere, a standard or traditional approach to problem-solving is the common means for understanding what is at hand. This is meant to say that understanding and then addressing issues is achieved via a rather narrow context of structured steps. Furthermore, taking action is customarily accomplished independently through a sub-national, national or supra-national method where it is rare that two levels of governance work together and even more rare that all three work in tandem. The tendency is to approach problems in an isolated manner where one level of governance acts on it while the others either accord their resources elsewhere or do not wholly cooperate with the first level for political, economic or other such reasons.

Even though there are strong and respected IIs, governance is predominantly constructed in a formalized manner that places a states' interests at the center. This behavior is not necessarily based solely on self-interests but arguably in large part occurs because of established norms that benefit the state first and foremost. This perpetuates an isolated approach to addressing problems which in turn exacerbates problems in the global commons. By virtue of their nature, the commons are the responsibility of no one entity, thus they rarely receive significant state support. Compounding the issue is the sense of ineffectiveness or even hopelessness experienced at the sub-national level where actions taken by communities to address commons problems often seem in vain, and at the supra-national level where little is accomplished without the support of states. This dispersion of effort unfortunately leads to a lack of a holistic approach to address problems of the global commons. An example is the Montreal Protocol of the 1970s that addressed CFCs and led many to optimistically believe that all levels of governance were gaining cohesion regarding the addressal of global problems (the

CFC issues was not yet recognized as a wicked problem) in the commons and that future action would follow suit. Unfortunately, that was not the case as demonstrated by the dearth of meaningful progress on issues such as Climate Change and marine debris. Further exacerbating the lack of cohesive international action is the fact that despite its global presence, relatively few average global citizens are aware of or concerned about the marine debris problem and the threat it poses. Because it is critical to the health of planetary ecosystems and the future of humanity, a novel, more integrated governance approach must supersede such norms of self-interest to addressing both existing and emerging problems.

Governance: Changing Norms and Behaviors

Because the traditional approach has proven largely unsuccessful and offers little optimism for addressing wicked problems – especially those of the commons – a new approach is vital, one that departs from well-established norms and creates understanding in a different light. Moreover, actors must reduce the limitations regarding the way a problem is conceived and all parties must be willing to think differently about how a problem is defined. Complicating the matter, norms are resilient:[210] Wayne Sandhotz summarized the difficulty of altering norms, stating they "remain robust because there are always parts of larger normative structures that support them."[211] Because norms are not independent and are tremendously complex themselves, often part of deep cultural ties or extended state policies or, importantly, perhaps part of an imbedded identity, associated norms and behaviors are extremely

[210] To amplify this, an entire edition of the *Journal of Global Security Studies* (2019) focuses on the robustness and contestation of norms.

[211] Wayne Sandhotz, "Norm Contestation, Robustness, and Replacement," *Journal of Global Security Studies* 4, no. 1 (2019): 146.

challenging to change. Fortunately, a norm does not have to necessarily change in its entirety; instead, it can be modified to varying degrees and still accomplish desirable change to mitigate the problem.

In the case of wicked problems, if a new approach to addressing such problems is to genuinely be considered, an openness to changing behaviors and norms is key. In addition, all levels of governance must work in concert to afford the best opportunity for managing wicked problems, especially those in the commons, because they involve every level of governance. Every participant who engages with the commons is affected, therefore, every participant must be actively engaged in addressing the problem.

It is a difficult task to establish norms because they must prove to be viable and durable over the long term. Once robust norms are established, they often become imbedded in identity and culture through practice. Arguably, the "identity of a state, not its power, matters more"[212] in the case of norms. The severity of this threat requires a modification to these established norms and a willingness to work on multiple-parallel fronts to forge a new path.

This project offers a necessary deviation from the norm of tackling wicked problems which is to seek progress not solutions (the norm) because one of the defining characteristics of a wicked problem is that there is no one solution. Instead, a more modest governance approach to address wicked problems is recommended - one that is progress-oriented instead of solution-centered. If the current norm continues, our understanding of wicked problems will remain limited and lead to the conclusion that a solution is unattainable. As such, instead of

[212] Sarah Percy, "What Makes a Norm Robust: The Norm against Female Combat," ibid.: 135.

focusing on what would be considered an inefficient use of effort and resources on a problem with no solution, the wicked problem is ignored while resources are reallocated to problem sets that provide more immediate satisfaction with near-term solutions. Understanding that if left unchecked, exponential growth heightens the existential threat of marine plastic debris, it must be attended to with an intent for progress instead of solutions.

Changing mindsets from solution-centered to progress-oriented will require modifications to norms that equate to a paradigm shift reflective of Thomas Kuhn's argument that one paradigm is contested and eventually discarded in favor of a new paradigm more suited to accommodate and explain contemporary phenomena.[213] While he addresses the progress of science as a series of scientific revolutions, his philosophy has long been held as equally applicable to the social sciences. Kuhn explains that a paradigm shift from commitments to mutual standards occurs when an anomaly "subverts the existing tradition of scientific practice"[214] and, while normal research or a quest for understanding follows that tradition of practice, he asserts that novel "and unsuspected phenomena are, however, repeatedly uncovered."[215] These alterations are "the tradition-shattering complements to the tradition-bound activity of normal science"[216] which supports the argument this project makes for a break from traditional thoughts and assumptions for both understanding and reevaluating how wicked problems are addressed. Modifying the norms of understanding and addressing

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[213] Thomas Kuhn, *The Structure of Scientific Revolutions* (Chicago: The University of Chicago Press, 1962). This is a general reference to his discussion on paradigm shifts.

[214] Ibid., 6.

[215] Ibid., 52.

[216] Ibid., 6.

wicked problems creates an opportunity to limit growth and potentially reduce critical elements of the problem. Finally, approaching a wicked problem such as marine debris with a progress-oriented focus instead of one that is solution-centered does not solely modify existing norms but also transforms and enriches the global community's opportunity for addressing such problems. Admittedly, this is not easy, but neither are problems such as marine debris which are characterized by diverse factors whose interdependence compounds negative effects throughout the system.

Examples: Norm Modifications and Systemic Progress

While reimagining how to think about wicked problems such as marine debris may seem a bridge too far, promising initiatives are underway to address this problem that, if aligned in a collective manner, offer great potential for actuating the premise of this paper. Organizations such as the WTO, UN, and EU are each positioned to play a prominent role in tackling marine debris. In recent years, the WTO has generated several forums to address the issue. On November 30, 2018 an official statement was made that, in a meeting of the Committee on Trade and Environment, "members heard discussions on managing plastic waste and attaining a circular economy where resources are recovered and recycled for maximum use,"[217] signifying a critical recognition of plastic's global impact.

Perhaps the most far-reaching global effort to date is the UN Environment Programme on Sustainable Development Goals (SDG) Target 14.1 which states, "by 2025, prevent and

[217] World Trade Organization, "Plastic Waste, 'Blue Economy' among Issues Taken up at Trade and Environment Committee," news release, November 30, 2018, https://www.wto.org/english/news_e/news18_e/envir_30nov18_e.htm.

significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution."[218] While this is more aspirational than actional, it engages all members of the UN by acknowledging that substantial efforts must be made to address the issue. Yet, as previously argued, this supra-national initiative must be coupled with the other levels of governance to realize meaningful behavioral change. As Lisa Martin and Beth Simmons point out in *Theories of Empirical Studies of International Institutions,* the connection between international institutions and domestic politics is powerful because "international institutions can influence state behavior by acting through domestic political channels."[219]

The EU has also made noteworthy strides to attend to plastics and marine plastic debris. The European Strategy for Plastics in a Circular Economy outlines rules for packaging and curbing plastic waste and managing plastics in port facilities, while encouraging innovation for more efficient recycling, and enhanced engagement with global partners. This international outreach is not limited to a particular level of governance and recognizes the need to engage on multiple levels for the greatest possibility of advancement. The EU's strategy has also implemented several legislative proposals like the March 2019 rules on single-use plastics that include a ban on designated single-use plastic products where alternatives exist on the market which attends to the exponential growth of plastic production. The rules also introduced

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[218] United Nations Environment Programme, "Sustainable Development Goals: Goal 14: Conserve and Sustainably Use the Oceans, Seas and Marine Resources: Goal 14 Targets," United Nations Environment Programme, https://www.un.org/sustainabledevelopment/oceans/.

[219] Lisa L. Martin and Beth A. Simmons, "Theories and Empirical Studies of International Institutions," *International Organization* 52, no. 4 (1998): 732.

extended responsibility plans that envelop the producer in the cost of litter clean-up which not only directly impacts the environment through regulatory measures but also strengthens recycling initiatives. Both actions limit the exponential growth of the marine plastic and its threat to the marine ecosystem.

An outcome of the EU measures that demonstrates progress is the European plastic refund scheme that incentivizes consumers to return their plastics via traditional collection points and through reverse vending machines. In both cases, the consumer receives a monetary refund or credit while the plastic is collected, recycled and often traced via a machine that tracks chemical markings and identifications. Plastics "pass through a marker-detection unit before being separated into those that have been used for food and drink and those that have not."[220] As many as 10 European countries have implemented this with success rates higher than 80 percent reported.[221]   Several immediately recognizable measures of advancement include: 1) the consumer is incentivized by receiving a nominal monetary return for their engagement which compounds as their efforts increase while at the same time costs to the industry remain negligible; 2) the consumer becomes more cognizant of the broader issues and is empowered not only to aid in the reduction of plastic waste but also in the reduction of the threat it poses to the environment; and 3) this technology affords an opportunity to link the returned plastic to the product manufacturer, who in turn is held accountable for the plastic they place on the market and its eventual recycling or disposal. The

[220] European Commission, "Top Marks for Plastic Bottle Recycling System," European Commission, https://ec.europa.eu/research/infocentre/article_en.cfm?artid=50229.

[221] Plastic Smart Cities, "Plastic Refund Scheme," World Wildlife Fund, https://plasticsmartcities.org/products/deposit-return-program.

introduction of a monetary value to plastic waste and the creation of individual empowerment incentivizes social responsibility that, with widespread social media, can modify attitudes and culture that hold norms so firmly in place.

These efforts also support the growing initiative of a circular economy, most notably advocated by the MacArthur Foundation whose work with the World Economic Forum for a New Plastic Economy "creates an effective after-use plastics economy…drastically reduce[s] leakage of plastics into natural systems…[and] decouple[s] plastics from fossil feedstocks."[222] This initiative contends that:

> "…the direct economic impact of implementing a Global Plastics Protocol would be sizeable, making recycling economically viable would also move the system into an upward spiral. There would be a financial incentive to collect and recycle more. Higher volumes would create further economies of scale and allow separation of purer grades, which, in turn, would increase yield. This would set a direct incentive for yet more collection and an indirect incentive for better material designs."[223]

Furthermore, state-level initiatives such as the numerous plastic bag bans described in Chapter 3 are promising but can be much more powerful and effective if coordinated among states and supported at both the sub-national and supra-national level.

An example of a sub-national level initiative is the work of the non-profit organization The Ocean Cleanup which seeks to address the problem of marine debris from a retardation and extraction viewpoint. This grassroots organization has gained international support in its efforts to develop a means to initially remove floating plastics and other debris from the ocean gyres and eventually to move beyond to the broader ocean. Additionally, the project seeks to

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[222] MacArthur et al., "The New Plastics Economy: Catalysing Action," 15.

[223] The World Economic Forum, System Initiative on Environment and Natural Resource Security, "The New Plastic Economy: Catalysing Action", January 2017, P26.

remove floating debris from rivers to stop the debris before it reaches the oceans. This project provides an excellent example of all three levels of governance working together to make progress on a wicked problem, receiving support from individuals, local and topic-focused communities, universities, states, MNCs and IIs. Their work led to the development and deployment of an innovative system to the Great Pacific Garbage Patch that has successfully returned tons of debris, primarily plastics, to shore where it is then sanitized and recycled into plastic granulate with the intention to transform it into new product. Similarly, the project has deployed several functional systems in rivers with the first in Jakarta, Indonesia. State and local cooperation is required to issue appropriate permits and to recruit employees to collect and properly transfer the captured materials.[224] Examples such as these indicate “there is a widespread view that the processes of governing now involve more diverse actors and more diverse organizational forms,”[225] indeed confirming that “the social complexity associated with WPs [wicked problems] means they can only be addressed if organizations engage with and involve stakeholders.”[226]

While each of these efforts is encouraging, they cannot be pursued independently if significant progress on this problem is to be made. Each initiative must not only be recognized by all entities but must be fully coordinated with all involved to maximize the utility of ideas and resources, although at times in opposition to sovereign states’ self-interests, prompting a

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[224] The Ocean Cleanup, "The Largest Cleanup in History," The Ocean Cleanup, https://theoceancleanup.com. Detailed information about the project mission, partners and progress can be found on the various tabs of The Ocean Cleanup’s website.

[225] Bevir, *Governance: A Very Short Introduction*, 3.

[226] Paul Willis, "From Humble Inquiry to Humble Intelligence: Confronting Wicked Problems and Augmenting Public Relations," *Public Relations Review* 42 (2016): 308.

change in culture that seeks a higher purpose. Tackling a wicked problem requires participation at all levels of governance since the goal is not to fix one isolated problem but to modify a very complex and dynamic system composed of variables that continuously interact and create vexing outcomes.

While a collaborative governance approach to wicked problems that modifies existing norms is ideal, it also poses challenges due to the unpredictability of actors and the lack of enforcement measures. Sundry interests and shifting priorities may sway actors to reevaluate their participation in progressive governance actions. However, the underpinning characteristic of norms is that unacceptable deviation from those norms generates a concomitant reputational cost. Reflecting on the past decade or so of climate change governance efforts, the US has participated in and even led numerous initiatives to address the problem helping establish new norms for international behavior. Yet in November 2019, in the face of changing national interests, the US formally notified the UN that it would withdraw from the Paris Accords. While the US was solely within its authority as a sovereign nation, the action "received criticism from countries, international organizations, city mayors, and industry leaders. Almost all the countries that issued a statement on the withdrawal resolved to continue the implementation of [the] Paris Agreement."[227] The international opposition to and displeasure with the US decision was obvious. In this case, the US was willing to risk the

[227] Zhang Yong-Xiang et al., "The Withdrawal of the U.S. From the Paris Agreement and Its Impact on Global Climate Change Governance," *Advances in Climate Change Research* 8, no. 4 (2017): 214-15.

reputational cost it subsequently encountered because national interest and priorities had changed.

There was, however, a significant feature of the Paris Agreement: it confirmed the "direction of international cooperation"[228] and encouraged consensus on norms and expectations for all actors to work together to achieve objectives to combat climate change. While the US can withdraw, it is obligated by international norms to explain why, which is the point where reputational costs are triggered. It is extremely difficult for an actor to abandon a commitment, particularly one it has had a leading role in developing, even if it is the most powerful country in the world, without eliciting noteworthy dissatisfaction from others adhering to the norm. If the majority believes the behavior is wrong, the actor must explain their reasoning for nonconforming. The resultant sense of accountability is a step toward governance where, perhaps, the actual accountability is in an actor's reputational loss and the subsequent effects it will endure should it decide to contest established or evolving norms.

When facing an existential threat that is also defined by "wicked problem" characteristics, the task of addressing the threat, in this case marine debris, is daunting. However, even though the totality of marine debris is a wicked problem, it does not mean inaccessibility; while developing a solution at the macro level is unlikely, making a difference at the micro level is achievable. Utilizing modeling and simulation provides greater insight into system parts and their dynamic interaction. This allows one or more variables to be manipulated and the feedback to be observed, which in turn provides not only a deeper

[228] Ibid., 214.

understanding of the dynamic interaction but also of the effect changes to a single variable can have on the system. Identifying variables of the marine debris wicked problem where something can be and is being done, demonstrates progress and provides policymakers and other actors with tools to tackle this complex problem from the micro level.

The way we conceive of a problem needs to be much less bounded. Instead of seeking a solution, seeking progress must be the goal. This requires new cultural thinking especially when addressing a wicked problem which, by definition, differs from the norm. While participation between actors is necessary in the process of governing, it is not always easy to facilitate. Interests among actors, most commonly associated with states, may range from very comparable to quite disparate where one actor's solution may be considered another's failure. Deviation from established or evolving norms subjects an actor to serious risk of reputational loss. Voluntary and unequal actor participation further renders decision-making difficult. Ultimately though, it is global participation that achieves desired outcomes for the good of all. It is therefore critical to create (or modify existing) norms that are robust, that evolve with changing situations, that remain relevant, and that will weather challenges even from major states. Intractable problems are inherently difficult to address, and governance actions need to be as multifaceted and dynamic as the problems themselves.

Contributions to the Extant Literature

There are several important and distinctive contributions that this study makes to the field of international relations generally, and to the broader transdisciplinary literature:

From a theoretical standpoint, this research creates a space for expansion from the underpinnings of traditional IR theory. It provides an entrance into the newer, less-recognized notion of complexity as defined by Wicked Problems Theory, according it further consideration as the international community grapples with increasing concerns related to ungoverned spaces.

The extant literature on marine debris primarily focuses on scientific studies designed to determine types of debris, areas of concentrated accumulation, volume, sources and deleterious effects. Here, the focus is on defining marine debris as a system in order to understand the dynamic interaction of its variables.

This study shows that traditional linear thinking about problems is insufficient for problems of tremendous magnitude and addresses the gap by offering a way to reconceptualize such challenges. Because this problem is unique, the first system dynamics model of its kind has been designed and presented to provide a heuristic tool for IR theorists and practitioners to understand the variable interactions of global commons problems. Because this model demonstrates the complexity of the system which no one single form of governance can manage it offers a bridge for developing new approaches to governance.

This study adds to the growing IR literature that employs modeling as a methodology and further expounds on its utility to enhance traditional IR qualitative analysis. This formal model design provides greater insight into the overall system and elucidates how that information can then be applied to achieve progress in tackling a wicked problem.

The extant literature views governance from a singular level, independent of other governance options. This study departs from that method by highlighting the benefits and potential of a collaborative, well-coordinated approach that involves all levels of governance in order to magnify the resources required to make progress on the complex problem of marine debris.

This study contributes to the literature on norms providing further considerations for their robust influence and a means by which they can be modified to facilitate progress on marine debris and, by extension, other wicked problems. Rather than arguing for far-reaching changes to norms (a difficult and prescriptive proposition), instead, a modest approach to norm adaptation is presented. It further supports assertions regarding the consequences of reputational cost when actors choose to oppose norms.

A final important contribution this study makes is the epistemological expansion of both understanding and addressing a wicked problem through a multidisciplinary approach. Collaborating across disciplines increases understanding of the marine debris problem and reconceptualizes the potential for progress by working outside IR's general framework.

Research Questions

As this chapter and project come to a close, a restatement of the research questions is beneficial to ground the preceding chapters and provide a reminder for the following review of the hypotheses. The primary research question is: Under what condition(s) does regulating debris in the marine commons pose unique governance challenges? This question led to the consideration of the application of the Wicked Problems theory for conceptualizing the complexity of marine debris and helping understand the governance challenges. With the incorporation of this theory a second question arose: Is the wicked problem of marine debris unsolvable?

Hypotheses

There are three suppositions made throughout this project. Each will now be briefly reexamined in order to evaluate their veracity and utility to the extent to which they are supported by the work within the study.

The first hypothesis presented in this study is: Marine debris is a wicked problem. This hypothesis is substantiated in Chapter 4 where Rittel and Webber's characteristics are delineated and their applicability to marine debris is affirmed. Specifically, the following five characteristics most strongly support this hypothesis: 1) There is no definitive formulation of the problem because actors' understanding of and ideas for solving this problem vary; 2) Solutions for marine debris, are not "true or false" but instead are "bad or good" because both the problem and solution depend upon the stakeholders' point of view; 3) Solutions to the marine debris problem will create consequences over an expanded period of time and space that are impossible to comprehensively track; therefore, no definitive test for a solution exists and every attempt matters; 4) Marine debris is unique – it has no one source, it is uncontained, unconfined, and easily transported; it appears in many forms, it is characterized by both known and unknown consequences, and the majority of the material is found in ungoverned waters; 5) Marine debris is a symptom of other problems - global economic pursuits and their consequences, and governance of the global commons – so, regulatory authority is difficult.

The second, and primary, hypothesis is: Wicked problems such as marine debris are inherently unique and because of their nature, extant models of governance fall short in tackling them. In addition to Rittel and Webber's declaration of the seventh characteristic (restated as the fourth characteristic in Hypothesis 1, this hypothesis is supported by the design of a causal loop diagram that illustrates marine debris not as a problem of singular origin but one of multiple variables within a complex and dynamic system. Analysis of the stock and flow simulation articulates the complicated and intricate interaction of the system components where some consequences are immediately recognizable while others are not as easily identifiable. It also supports the claim that a wicked problem is unconstrained as demonstrated by the magnitude of the problem and that, in the absence of sufficient governance, results in exponential growth.

This hypothesis is further supported by a review of current governance structures and actions taken to combat the problem. While many are beneficial, most have severe limitations, confined by the method by which problems are traditionally understood and thus the concepts for addressing them. As a result, governance actions presently in place are inadequate to create ample balancing effects to the marine debris system. Therefore, this study demonstrates that because none of the existing regulations have made a meaningful impact on the marine debris problem at a global level, current models of governance are insufficient and must be reconceptualized.

A final hypothesis is presented: Contrary to existing norms, governance can be adapted to confront marine debris with meaningful results and, by extension, other wicked problems, through a reframed progress-centered versus solution-oriented approach. This hypothesis is affirmed in the preceding sections of Chapter 6 as well as through the articulation of the model. Current epistemology associated with problems is entrenched in the norm of linear thinking. Yet, problems such as marine debris are unbounded, a characteristic that makes them wicked. Traditional linear thinking has produced limited and universally uncoordinated efforts to address the issue as illustrated by the individual regulatory measures in Chapter 3. However, they have not proven effective in combating non-linear problems since they do not consider the dynamic interaction of the whole system. Instead, the linear approach is solution-centered and when definitive solutions are not possible - a characteristic of a wicked problem - the norms that bound governance are inadequate.

While existing norms are robust, the very influence and culture that maintains them can also be used to modify them to better comprehend marine debris and institute measures that are progress-centered. Modifying the norms of governance – while extremely difficult to do - expands creativity for conceptualizing problems and magnifies associated epistemology. A fully coordinated global agenda best serves everyone’s interests over self-interest. Contrary to current governance’s linear approach to problems – often an “all or nothing” norm – a progressive approach will allow for significant steps to balance the marine debris system. This emphasizes the importance of Rittel and Webber’s tenth characteristic which places responsibility on planners, and by extension governance, to act on behalf of the people they serve.

Limitations of the Study

While there are several limitations of this study, they do not invalidate the contribution of this unique model or the extent to which the outcomes can be employed. Three areas that represent such limitations are availability of sufficient and consistent data, choice of variables and quantifiable impact of plastic on the marine environment.

First, consistent plastic data is absent for evaluating the volume currently in the ocean and the definitive threat it poses. Random surface samples have been taken to estimate microplastics and other varieties in various portions of the ocean; however, they neither account for all types of plastic nor for plastics below the surface, to include the seabed. Additionally, the design for data collection has generally been one specific to each project, not based on a global or even national standard. While a few studies have been conducted to estimate the amount of plastic produced globally since inception and, extrapolated to determine what percentage has entered the ocean, they lack specificity with several Mt of deviation.[229] These studies are not structured by guidelines for data collection universally accepted and employed.

While this study has utilized 14 variables to represent a system dynamics model of marine debris, there are several other variables available for inclusion. Variables such as wind, surface currents, thermohaline circulation, landfill waste management, types of plastic, aquatic ingestion, and human ingestion are additional considerations for application within the model. The addition or subtraction of each variable will change the dynamic interaction of the

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[229] Geyer, Jambeck, and Law, "Production, Use, and Fate of All Plastics Ever Made," 1.

simulation and the results that it produces. The choice of variables is determined by the model designer whose mode of reasoning is generally based on what is most plausible within their perspective, as Rittel and Webber's ninth characteristic asserts. Therefore, this model, as with all wicked problem models can have significant variation depending upon the variables chosen.

Carrying out more extensive research and more in-depth analysis would help quantify the impact of plastics in the marine environment. Since there are numerous ecosystems within the totality of the broader marine environment, extensive analysis (designed to adhere to a consistent global analysis protocol associated with the concern in the first limitation) could be conducted to assess the impacts on individual ecosystems. This is likely to be further constrained by both time and money, considering the size of the ocean; however, determinations from such findings would be useful to illuminate much greater understanding of the extent to which plastic affects the ocean at every ecosystem level. This would be beneficial not just within the marine environment but throughout the broader planetary ecosystem since all living organisms are reliant upon the ocean either directly or indirectly.

Recommendations and Future Work

This work has been largely based on notional values derived from a very limited pool of plastics data. Due to the identified threat plastics impose on the marine environment, and the planet at large, concerted efforts must be made to expand the data pool. Not only is more data necessary to improve modeling, it would be most beneficial if that data were collected in concert with a universal standard. Due to the omnipresence of plastic, data collection across the globe would be useful to the broader research if each individual effort were based on a set of universally recognized guidelines for collection; therefore, researchers and policymakers should strive to develop such a standard. Furthermore, research and understanding would be greatly enhanced if data collection was coordinated to avert redundancy, emphasizes on collection based on a precedence of importance, to prioritize funding, and to identify gaps in collection.

Additional modeling would prove very useful in furthering the ideas of this project. Project constraints allowed only one set of variables to be used for the model design of this marine debris system and only a few of those variables were manipulated to simulate intervention. Continuing the simulation of variable intervention within the current design, utilizing various other combinations, will produce an increased pool of data to expand the understanding of the system's dynamics. Further, a comprehensive analysis of an expanded variable set would elucidate the system's growth as well as its balancing potential. Other model applications may also aid research on marine plastic debris, consequently informing individuals, corporations and government policymakers to better incorporate measures for balancing the increasing threat currently posed by marine debris.

Finally, future research should focus on consumer awareness of the impact their plastic consumption has, not only on the marine ecosystem and larger global environment, but also its deleterious effects on them directly. The more consumers comprehend these threats, the more change they will demand from both producers and governance alike.

Concluding Remarks

This project aims to characterize marine debris as a wicked problem and explores the complexity of governance of the global ocean commons. Marine debris is inherently unique and because of its nature, extant models of governance are inadequate to address this problem. Further, it suggests that by modifying existing norms, governance can take steps towards tackling wicked problems through collaboration at all levels and by adopting a progress-centered versus solution-oriented approach. Rather than resolving a distinct and finite problem, this approach proposes to modify a very complex and dynamic system composed of variables that continuously interact and create vexing outcomes. Despite their "wickedness," wicked problems do not need to remain inaccessible. Working through multiple levels of governance increases accessibility to address a problem that appears otherwise impossible to solve. Utilization of a formal system dynamics model allows all actors to conceive of the problem of marine debris in a less bounded, more creative manner. Undaunted by its complexity, and unconstrained by the need to find a solution, stakeholders are free to create "wicked ideas" for wicked problems such as marine debris.

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APPENDIX

SIMULATION TABLES

Time (Month)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
GPP : Intervention	5	5.68108	6.14773	6.49727	6.77242	6.99653	7.18395	7.34415	7.48372	7.60739	7.71866	7.82014	7.91386	8.00136	8.08388	8.16235	8.23755	8.31008	8.38042	8.44896	8.51602
GPP : Non-Intervention	5	5.70722	6.19155	6.55345	6.83671	7.06519	7.25363	7.41181	7.54657	7.66288	7.76446	7.85416	7.93416	8.0062	8.07167	8.13168	8.18711	8.2387	8.28706	8.33266	8.37592
Consumption : Intervention	4.8	4.79795	4.80607	4.82097	4.8408	4.86434	4.89078	4.91952	4.9501	4.9822	5.01554	5.04992	5.08516	5.12114	5.15776	5.19491	5.23254	5.27058	5.30898	5.3477	5.3867
Consumption : Non-Intervention	4.8	4.77181	4.75094	4.73512	4.72306	4.71396	4.70721	4.70241	4.69922	4.69739	4.69672	4.69705	4.69824	4.70019	4.70281	4.70602	4.70976	4.71398	4.71863	4.72368	4.72908
Waste : Intervention	4	4.04334	4.0864	4.12915	4.1716	4.21377	4.25568	4.29732	4.33873	4.3799	4.42084	4.46156	4.50206	4.54236	4.58244	4.62232	4.66199	4.70147	4.74074	4.77982	4.81869
Waste : Non-Intervention	4	4.04334	4.086	4.12791	4.16906	4.20945	4.24909	4.288	4.32617	4.36363	4.4004	4.43648	4.47189	4.50665	4.54076	4.57424	4.60711	4.63937	4.67105	4.70214	4.73267
Threat to Ecosystem : Intervention	0.2	0.23763	0.27607	0.31534	0.35544	0.39636	0.43812	0.48071	0.52414	0.56841	0.61352	0.65948	0.70629	0.75396	0.80248	0.85186	0.90211	0.95322	1.0052	1.05805	1.11178
Threat to Ecosystem : Non-Intervention	0.2	0.23763	0.27607	0.31534	0.35541	0.39628	0.43795	0.48041	0.52365	0.56766	0.61244	0.65798	0.70427	0.75129	0.79906	0.84754	0.89675	0.94666	0.99728	1.04859	1.10059

21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
8.58185	8.64666	8.71061	8.77384	8.83645	8.89855	8.96019	9.02144	9.08236	9.14296	9.2033	9.26339	9.32325	9.38291	9.44237	9.50165	9.56074	9.61967	9.67843	9.73702	9.79546	9.85373	9.91184	9.9698	10.0276
8.41717	8.45669	8.49473	8.53146	8.56705	8.60165	8.63536	8.66829	8.70052	8.73211	8.76313	8.79363	8.82365	8.85323	8.8824	8.91118	8.93961	8.9677	8.99548	9.02294	9.05013	9.07703	9.10367	9.13005	9.15619
5.42596	5.46545	5.50515	5.54504	5.5851	5.62532	5.66568	5.70617	5.74678	5.7875	5.82832	5.86923	5.91022	5.95129	5.99242	6.03362	6.07486	6.11615	6.15748	6.19884	6.24022	6.28163	6.32304	6.36446	6.40589
4.73482	4.74087	4.74721	4.75381	4.76066	4.76774	4.77505	4.78257	4.79028	4.79818	4.80627	4.81452	4.82294	4.83151	4.84023	4.84909	4.85809	4.86722	4.87647	4.88584	4.89533	4.90493	4.91464	4.92445	4.93435
4.85737	4.89585	4.93414	4.97223	5.01012	5.04781	5.08531	5.12261	5.15972	5.19663	5.23334	5.26986	5.30618	5.3423	5.37822	5.41394	5.44947	5.4848	5.51993	5.55486	5.58959	5.62412	5.65846	5.69259	5.72652
4.76264	4.79207	4.82097	4.84934	4.87721	4.90458	4.93147	4.95787	4.98381	5.00929	5.03433	5.05893	5.08311	5.10686	5.13022	5.15317	5.17573	5.19791	5.21972	5.24117	5.26226	5.28301	5.30342	5.32349	5.34325
1.16638	1.22187	1.27824	1.33549	1.39363	1.45266	1.51258	1.5734	1.63511	1.69771	1.76122	1.82563	1.89094	1.95715	2.02427	2.09229	2.16122	2.23106	2.3018	2.37346	2.44602	2.51949	2.59388	2.66917	2.74538
1.15326	1.2066	1.26061	1.31526	1.37056	1.4265	1.48307	1.54026	1.59807	1.65648	1.71549	1.77509	1.83528	1.89604	1.95737	2.01927	2.08172	2.14471	2.20825	2.27232	2.33692	2.40204	2.46768	2.53382	2.60047

46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70
10.0852	10.1427	10.2	10.2572	10.3141	10.3709	10.4276	10.484	10.5403	10.5964	10.6524	10.7081	10.7636	10.819	10.8742	10.9292	10.984	11.0385	11.0929	11.1471	11.2011	11.2549	11.3084	11.3617	11.4149
9.18208	9.20775	9.23319	9.25841	9.28342	9.30823	9.33283	9.35723	9.38144	9.40547	9.4293	9.45296	9.47644	9.49974	9.52288	9.54584	9.56864	9.59128	9.61376	9.63609	9.65826	9.68028	9.70216	9.72389	9.74547
6.4473	6.48871	6.5301	6.57146	6.6128	6.6541	6.69536	6.73658	6.77774	6.81885	6.8599	6.90088	6.94179	6.98262	7.02336	7.06402	7.10459	7.14506	7.18542	7.22568	7.26582	7.30585	7.34576	7.38553	7.42518
4.94435	4.95444	4.96462	4.97487	4.98521	4.99562	5.00611	5.01666	5.02728	5.03796	5.04871	5.05951	5.07037	5.08127	5.09223	5.10324	5.11429	5.12538	5.13652	5.14769	5.1589	5.17014	5.18141	5.19271	5.20404
5.76025	5.79378	5.82712	5.86025	5.89317	5.9259	5.95843	5.99075	6.02288	6.0548	6.08651	6.11803	6.14934	6.18046	6.21137	6.24207	6.27257	6.30287	6.33297	6.36286	6.39255	6.42204	6.45133	6.48041	6.50928
5.36269	5.38182	5.40065	5.41919	5.43744	5.45541	5.4731	5.49054	5.50771	5.52462	5.54129	5.55772	5.57391	5.58987	5.60561	5.62112	5.63642	5.65151	5.6664	5.68109	5.69558	5.70989	5.72401	5.73794	5.7517
2.8225	2.90053	2.97947	3.05932	3.14008	3.22176	3.30434	3.38783	3.47223	3.55753	3.64375	3.73087	3.81889	3.90782	3.99765	4.08838	4.18001	4.27253	4.36596	4.46027	4.55548	4.65158	4.74857	4.84645	4.94521
2.66761	2.73524	2.80335	2.87194	2.94101	3.01054	3.08052	3.15097	3.22186	3.2932	3.36497	3.43719	3.50982	3.58289	3.65637	3.73026	3.80457	3.87928	3.95439	4.0299	4.1058	4.18209	4.25876	4.33581	4.41323

71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
11.4678	11.5205	11.5729	11.6251	11.6771	11.7289	11.7805	11.8318	11.8828	11.9337	11.9843	12.0346	12.0847	12.1345	12.1841	12.2335	12.2826	12.3314	12.38	12.4283	12.4764	12.5241	12.5717	12.6189	12.6659
9.76692	9.78822	9.80939	9.83043	9.85134	9.87211	9.89276	9.91329	9.93369	9.95396	9.97412	9.99416	10.0141	10.0339	10.0536	10.0732	10.0927	10.112	10.1313	10.1504	10.1695	10.1884	10.2073	10.226	10.2447
7.46469	7.50406	7.54328	7.58236	7.62128	7.66004	7.69864	7.73707	7.77533	7.81342	7.85133	7.88905	7.92659	7.96394	8.00109	8.03804	8.07479	8.11134	8.14767	8.1838	8.2197	8.25539	8.29085	8.32609	8.3611
5.2154	5.22678	5.23819	5.24961	5.26105	5.27252	5.28399	5.29548	5.30699	5.31851	5.33003	5.34157	5.35311	5.36466	5.37622	5.38777	5.39934	5.4109	5.42246	5.43402	5.44559	5.45714	5.4687	5.48025	5.49179
6.53796	6.56643	6.59469	6.62276	6.65061	6.67827	6.70572	6.73297	6.76002	6.78686	6.8135	6.83993	6.86616	6.89219	6.91802	6.94364	6.96906	6.99428	7.01929	7.0441	7.06871	7.09312	7.11732	7.14133	7.16513
5.76529	5.77871	5.79197	5.80506	5.818	5.83078	5.84342	5.85591	5.86825	5.88046	5.89253	5.90447	5.91628	5.92796	5.93951	5.95095	5.96227	5.97347	5.98456	5.99553	6.0064	6.01717	6.02783	6.03838	6.04884
5.04485	5.14537	5.24677	5.34904	5.45219	5.55621	5.66109	5.76683	5.87344	5.98091	6.08923	6.1984	6.30842	6.41929	6.531	6.64355	6.75693	6.87115	6.98619	7.10206	7.21875	7.33625	7.45457	7.5737	7.69363
4.49103	4.5692	4.64773	4.72662	4.80587	4.88547	4.96542	5.04572	5.12636	5.20735	5.28867	5.37032	5.45231	5.53462	5.61726	5.70022	5.7835	5.8671	5.95101	6.03524	6.11977	6.20461	6.28976	6.37521	6.46095

96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
12.7126	12.7591	12.8053	12.8512	12.8968	12.9421	12.9872	13.0319	13.0764	13.1206	13.1646	13.2082	13.2515	13.2946	13.3374	13.3798	13.422	13.4639	13.5055	13.5467	13.5877	13.6284	13.6688	13.7089	13.7486
10.2632	10.2817	10.3001	10.3183	10.3365	10.3546	10.3726	10.3905	10.4083	10.4261	10.4437	10.4613	10.4788	10.4962	10.5135	10.5307	10.5479	10.565	10.582	10.5989	10.6157	10.6325	10.6492	10.6658	10.6823
8.39588	8.43042	8.46472	8.49878	8.53259	8.56616	8.59948	8.63254	8.66535	8.6979	8.73019	8.76222	8.79398	8.82547	8.85669	8.88764	8.91831	8.94871	8.97883	9.00867	9.03822	9.06749	9.09648	9.12517	9.15358
5.50333	5.51486	5.52639	5.5379	5.54941	5.5609	5.57239	5.58386	5.59532	5.60676	5.6182	5.62962	5.64102	5.65241	5.66378	5.67513	5.68647	5.69779	5.70909	5.72037	5.73164	5.74288	5.7541	5.76531	5.77649
7.18873	7.21213	7.23533	7.25832	7.28112	7.30371	7.32611	7.34831	7.3703	7.3921	7.4137	7.4351	7.4563	7.4773	7.4981	7.51871	7.53912	7.55933	7.57935	7.59917	7.6188	7.63823	7.65746	7.6765	7.69535
6.0592	6.06947	6.07965	6.08973	6.09972	6.10963	6.11945	6.12919	6.13884	6.14842	6.15792	6.16734	6.17668	6.18595	6.19514	6.20427	6.21332	6.22231	6.23123	6.24008	6.24887	6.25759	6.26626	6.27485	6.28339
7.81436	7.93589	8.05821	8.18132	8.30521	8.42989	8.55534	8.68155	8.80854	8.93628	9.06479	9.19404	9.32404	9.45479	9.58627	9.71848	9.85142	9.98509	10.1195	10.2546	10.3904	10.5269	10.6641	10.802	10.9406
6.547	6.63333	6.71997	6.80689	6.8941	6.9816	7.06938	7.15744	7.24579	7.33441	7.42331	7.51249	7.60194	7.69166	7.78164	7.8719	7.96242	8.05321	8.14426	8.23557	8.32714	8.41897	8.51106	8.6034	8.69599

Time (Month)	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140
GPP : Intervention	13.79	13.8273	13.8661	13.9047	13.9429	13.9809	14.0185	14.0558	14.0928	14.1295	14.1658	14.2019	14.2377	14.2731	14.3082	14.343	14.3775	14.4116	14.4455	14.479
GPP : Non-Intervention	10.7	10.7152	10.7315	10.7478	10.764	10.7801	10.7961	10.8121	10.828	10.8438	10.8596	10.8753	10.8909	10.9065	10.922	10.9375	10.9528	10.9681	10.9834	10.9986
Consumption : Intervention	9.182	9.20951	9.23703	9.26426	9.29119	9.31783	9.34416	9.37018	9.39591	9.42133	9.44645	9.47126	9.49576	9.51996	9.54384	9.56742	9.59069	9.61364	9.63628	9.65861
Consumption : Non-Intervention	5.788	5.79879	5.8099	5.821	5.83207	5.84312	5.85414	5.86514	5.87612	5.88707	5.898	5.9089	5.91978	5.93063	5.94146	5.95226	5.96303	5.97378	5.9845	5.99519
Waste : Intervention	7.714	7.73246	7.75073	7.7688	7.78668	7.80437	7.82187	7.83918	7.8563	7.87323	7.88997	7.90653	7.92289	7.93907	7.95506	7.97086	7.98648	8.00192	8.01717	8.03223
Waste : Non-Intervention	6.292	6.30029	6.30866	6.31696	6.32522	6.33341	6.34156	6.34965	6.35768	6.36567	6.37361	6.38149	6.38933	6.39712	6.40486	6.41255	6.4202	6.4278	6.43536	6.44288
Threat to Ecosystem : Intervention	11.08	11.2198	11.3604	11.5016	11.6436	11.7862	11.9294	12.0733	12.2178	12.3629	12.5087	12.6551	12.8021	12.9497	13.098	13.2468	13.3962	13.5462	13.6968	13.8479
Threat to Ecosystem : Non-Intervention	8.789	8.88193	8.97528	9.06887	9.16271	9.2568	9.35113	9.4457	9.54052	9.63557	9.73087	9.8264	9.92217	10.0182	10.1144	10.2109	10.3076	10.4045	10.5017	10.5991

141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165
14.5122	14.5451	14.5777	14.6099	14.6418	14.6735	14.7047	14.736	14.7663	14.7967	14.8267	14.8563	14.8857	14.9147	14.9434	14.9718	14.9999	15.0276	15.055	15.0821	15.1089	15.1353	15.1615	15.1873	15.2128
11.0137	11.0288	11.0438	11.0587	11.0736	11.0884	11.1032	11.118	11.1325	11.1471	11.1616	11.176	11.1904	11.2048	11.2191	11.2333	11.2475	11.2616	11.2757	11.2897	11.3036	11.3175	11.3313	11.3451	11.3588
9.68063	9.70233	9.72372	9.74479	9.76555	9.786	9.80612	9.8259	9.84543	9.86461	9.88347	9.90202	9.92025	9.93817	9.95577	9.97305	9.99002	10.0067	10.023	10.039	10.0547	10.0701	10.0852	10.1	10.1144
6.00586	6.0165	6.02711	6.03769	6.04825	6.05878	6.06928	6.0798	6.0902	6.10061	6.111	6.12136	6.13169	6.14199	6.15226	6.1625	6.17271	6.1829	6.19305	6.20317	6.21327	6.22333	6.23337	6.24337	6.25335
8.04711	8.06181	8.07633	8.09066	8.10482	8.11879	8.13259	8.1462	8.15964	8.1729	8.18598	8.19888	8.21161	8.22417	8.23655	8.24875	8.26079	8.27265	8.28434	8.29586	8.30721	8.31838	8.32939	8.34024	8.35091
6.45034	6.45777	6.46515	6.4725	6.4798	6.48705	6.49427	6.5015	6.50859	6.51569	6.52275	6.52977	6.53676	6.5437	6.55062	6.55749	6.56433	6.57113	6.5779	6.58463	6.59132	6.59799	6.60462	6.61121	6.61777
13.9996	14.1519	14.3048	14.4582	14.6121	14.7666	14.9216	15.077	15.2332	15.3898	15.5468	15.7044	15.8625	16.0211	16.1801	16.3397	16.4997	16.6602	16.8211	16.9825	17.1443	17.3066	17.4694	17.6325	17.7961
10.6967	10.7945	10.8926	10.9909	11.0894	11.1882	11.2871	11.386	11.4857	11.5853	11.6852	11.7852	11.8855	11.986	12.0867	12.1876	12.2887	12.39	12.4916	12.5933	12.6953	12.7975	12.8998	13.0024	13.1052

166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190
15.2379	15.2627	15.2873	15.3115	15.3353	15.3589	15.3821	15.405	15.4276	15.4499	15.4718	15.4935	15.5148	15.5358	15.5565	15.5768	15.5969	15.6166	15.636	15.6551	15.6739	15.6924	15.7106	15.7284	15.7459
11.3725	11.3861	11.3997	11.4132	11.4267	11.4401	11.4534	11.4667	11.48	11.4932	11.5063	11.5194	11.5324	11.5454	11.5583	11.5712	11.5841	11.5968	11.6096	11.6223	11.6349	11.6475	11.66	11.6725	11.6849
10.1285	10.1424	10.1559	10.1691	10.182	10.1946	10.2068	10.2188	10.2305	10.2418	10.2529	10.2636	10.2741	10.2842	10.294	10.3036	10.3128	10.3218	10.3304	10.3387	10.3468	10.3545	10.362	10.3692	10.3761
6.26329	6.27321	6.28309	6.29295	6.30277	6.31256	6.32233	6.33206	6.34176	6.35143	6.36107	6.37069	6.38027	6.38981	6.39933	6.40882	6.41828	6.42771	6.4371	6.44647	6.4558	6.46511	6.47438	6.48362	6.49284
8.36142	8.37176	8.38194	8.39195	8.4018	8.41149	8.42101	8.43037	8.43958	8.44862	8.4575	8.46623	8.4748	8.48321	8.49147	8.49957	8.50752	8.51531	8.52295	8.53044	8.53778	8.54497	8.55201	8.5589	8.56564
6.6243	6.6308	6.63726	6.64369	6.65009	6.65646	6.66279	6.6691	6.67537	6.68161	6.68783	6.69401	6.70016	6.70628	6.71238	6.71844	6.72448	6.73048	6.73646	6.74241	6.74833	6.75423	6.76009	6.76593	6.77174
17.9601	18.1245	18.2893	18.4545	18.6202	18.7862	18.9526	19.1193	19.2865	19.454	19.6218	19.79	19.9586	20.1275	20.2967	20.4663	20.6362	20.8064	20.9769	21.1477	21.3189	21.4903	21.662	21.834	22.0063
13.2082	13.3114	13.4148	13.5184	13.6222	13.7262	13.8304	13.9348	14.0394	14.1442	14.2492	14.3544	14.4597	14.5653	14.6711	14.777	14.8832	14.9895	15.096	15.2028	15.3097	15.4168	15.524	15.6315	15.7392

191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215
15.7632	15.7801	15.7967	15.813	15.829	15.8447	15.86	15.8751	15.8899	15.9043	15.9185	15.9324	15.9459	15.9592	15.9721	15.9848	15.9972	16.0092	16.021	16.0325	16.0436	16.0545	16.0651	16.0754	16.0855
11.6973	11.7096	11.7219	11.7342	11.7463	11.7585	11.7706	11.7826	11.7946	11.8066	11.8185	11.8303	11.8421	11.8539	11.8656	11.8773	11.8889	11.9005	11.912	11.9235	11.9349	11.9463	11.9577	11.969	11.9802
10.3827	10.389	10.395	10.4007	10.4062	10.4113	10.4162	10.4208	10.4252	10.4292	10.433	10.4365	10.4397	10.4427	10.4454	10.4478	10.45	10.4519	10.4535	10.4549	10.456	10.4568	10.4574	10.4578	10.4579
6.50202	6.51117	6.52029	6.52938	6.53843	6.54746	6.55646	6.56542	6.57436	6.58326	6.59214	6.60098	6.60979	6.61858	6.62733	6.63605	6.64474	6.6534	6.66203	6.67063	6.6792	6.68774	6.69625	6.70472	6.71317
8.57224	8.57869	8.58499	8.59116	8.59717	8.60305	8.60878	8.61437	8.61982	8.62513	8.63031	8.63534	8.64024	8.64501	8.64963	8.65413	8.65849	8.66271	8.66681	8.67077	8.67461	8.67831	8.68189	8.68534	8.68866
6.77753	6.78328	6.78901	6.79472	6.80039	6.80604	6.81167	6.81726	6.82283	6.82838	6.8339	6.8394	6.84487	6.85031	6.85573	6.86112	6.86649	6.87184	6.87716	6.88246	6.88773	6.89298	6.8982	6.9034	6.90858
22.1788	22.3516	22.5247	22.698	22.8716	23.0454	23.2194	23.3937	23.5682	23.743	23.9179	24.0931	24.2684	24.444	24.6198	24.7957	24.9718	25.1481	25.3246	25.5012	25.6781	25.855	26.0321	26.2094	26.3868
15.847	15.955	16.0632	16.1716	16.2802	16.3889	16.4979	16.607	16.7163	16.8258	16.9354	17.0452	17.1552	17.2654	17.3758	17.4863	17.597	17.7079	17.8189	17.9302	18.0416	18.1531	18.2649	18.3768	18.4888

216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240
16.0952	16.1046	16.1138	16.1227	16.1312	16.1396	16.1476	16.1553	16.1628	16.17	16.1769	16.1835	16.1899	16.196	16.2018	16.2073	16.2126	16.2176	16.2224	16.2268	16.231	16.235	16.2387	16.2421	16.2453
11.9914	12.0026	12.0137	12.0248	12.0358	12.0468	12.0577	12.0686	12.0795	12.0903	12.1011	12.1118	12.1225	12.1331	12.1437	12.1542	12.1647	12.1752	12.1856	12.196	12.2063	12.2166	12.2269	12.2371	12.2473
10.4577	10.4573	10.4566	10.4557	10.4546	10.4532	10.4516	10.4497	10.4476	10.4452	10.4427	10.4398	10.4368	10.4335	10.4301	10.4263	10.4224	10.4182	10.4139	10.4093	10.4044	10.3994	10.3942	10.3887	10.3831
6.72159	6.72998	6.73833	6.74666	6.75496	6.76322	6.77146	6.77967	6.78784	6.79599	6.80411	6.81219	6.82025	6.82828	6.83628	6.84424	6.85218	6.86009	6.86797	6.87582	6.88364	6.89144	6.8992	6.90693	6.91463
8.69186	8.69493	8.69788	8.7007	8.7034	8.70598	8.70844	8.71078	8.71299	8.71509	8.71708	8.71894	8.72069	8.72233	8.72385	8.72526	8.72655	8.72774	8.72881	8.72977	8.73062	8.73137	8.732	8.73253	8.73295
6.91373	6.91886	6.92397	6.92905	6.93411	6.93914	6.94416	6.94915	6.95412	6.95906	6.96399	6.96889	6.97377	6.97862	6.98346	6.98827	6.99306	6.99783	7.00258	7.0073	7.01201	7.01669	7.02135	7.02599	7.03061
26.5643	26.742	26.9198	27.0977	27.2757	27.4538	27.6321	27.8104	27.9889	28.1674	28.346	28.5247	28.7035	28.8823	29.0612	29.2402	29.4192	29.5983	29.7775	29.9566	30.1359	30.3151	30.4944	30.6737	30.853
18.6011	18.7135	18.8261	18.9388	19.0517	19.1648	19.278	19.3914	19.505	19.6187	19.7326	19.8467	19.9609	20.0752	20.1898	20.3045	20.4193	20.5343	20.6495	20.7648	20.8802	20.9959	21.1117	21.2276	21.3437

Time (Month)	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260
GPP : Intervention	16.25	16.2508	16.2532	16.2554	16.2573	16.2589	16.2603	16.2615	16.2624	16.263	16.2634	16.2636	16.2635	16.2632	16.2627	16.2619	16.2608	16.2596	16.2581	16.2564
GPP : Non-Intervention	12.26	12.2675	12.2775	12.2875	12.2975	12.3074	12.3173	12.3271	12.3369	12.3467	12.3564	12.3661	12.3757	12.3853	12.3949	12.4044	12.4139	12.4233	12.4327	12.442
Consumption : Intervention	10.38	10.3711	10.3649	10.3584	10.3517	10.3448	10.3378	10.3305	10.3231	10.3154	10.3076	10.2996	10.2914	10.283	10.2745	10.2657	10.2568	10.2477	10.2385	10.229
Consumption : Non-Intervention	6.922	6.92995	6.93757	6.94516	6.95272	6.96025	6.96775	6.97522	6.98266	6.99008	6.99746	7.00482	7.01215	7.01945	7.02672	7.03397	7.04118	7.04837	7.05553	7.06266
Waste : Intervention	8.733	8.73349	8.7336	8.7336	8.73351	8.73331	8.73302	8.73262	8.73212	8.73153	8.73084	8.73005	8.72917	8.72819	8.72712	8.72596	8.7247	8.72335	8.72191	8.72037
Waste : Non-Intervention	7.035	7.03979	7.04434	7.04888	7.0534	7.05789	7.06237	7.06682	7.07125	7.07567	7.08006	7.08443	7.08879	7.09312	7.09744	7.10173	7.10601	7.11026	7.1145	7.11872
Threat to Ecosystem : Intervention	31.03	31.2118	31.3911	31.5705	31.7499	31.9292	32.1086	32.288	32.4673	32.6466	32.8259	33.0052	33.1844	33.3636	33.5427	33.7218	33.9009	34.0799	34.2589	34.4378
Threat to Ecosystem : Non-Intervention	21.46	21.5763	21.6929	21.8096	21.9264	22.0434	22.1605	22.2778	22.3953	22.5129	22.6306	22.7485	22.8665	22.9847	23.103	23.2215	23.3401	23.4588	23.5777	23.6968

261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285
16.2544	16.2523	16.2499	16.2472	16.2444	16.2413	16.238	16.2345	16.2308	16.2268	16.2227	16.2183	16.2137	16.2089	16.2039	16.1987	16.1933	16.1877	16.1818	16.1758	16.1696	16.1632	16.1566	16.1497	16.1427
12.4514	12.4606	12.4699	12.4791	12.4883	12.4974	12.5065	12.5155	12.5245	12.5335	12.5424	12.5513	12.5602	12.569	12.5778	12.5866	12.5953	12.6039	12.6126	12.6212	12.6297	12.6383	12.6468	12.6552	12.6636
10.2194	10.2096	10.1997	10.1896	10.1793	10.1689	10.1583	10.1476	10.1367	10.1256	10.1144	10.1031	10.0916	10.0799	10.0681	10.0562	10.0441	10.0319	10.0196	10.0071	9.99446	9.9817	9.96882	9.9558	9.94266
7.06976	7.07684	7.08388	7.0909	7.09789	7.10486	7.11179	7.1187	7.12558	7.13244	7.13926	7.14606	7.15283	7.15958	7.16629	7.17298	7.17965	7.18628	7.19289	7.19947	7.20603	7.21256	7.21906	7.22553	7.23198
8.71875	8.71704	8.71525	8.71336	8.71139	8.70933	8.70719	8.70496	8.70265	8.70026	8.69778	8.69522	8.69259	8.68987	8.68707	8.6842	8.68124	8.67821	8.67511	8.67192	8.66867	8.66533	8.66193	8.65845	8.6549
7.12291	7.12709	7.13125	7.13539	7.13951	7.14361	7.1477	7.15176	7.15581	7.15984	7.16385	7.16784	7.17181	7.17577	7.1797	7.18362	7.18752	7.1914	7.19527	7.19911	7.20294	7.20675	7.21055	7.21432	7.21808
34.6166	34.7954	34.9741	35.1527	35.3312	35.5097	35.6881	35.8664	36.0446	36.2227	36.4007	36.5786	36.7564	36.9341	37.1117	37.2891	37.4665	37.6437	37.8208	37.9978	38.1747	38.3514	38.528	38.7044	38.8807
23.8159	23.9352	24.0547	24.1743	24.294	24.4139	24.5339	24.654	24.7743	24.8947	25.0153	25.136	25.2568	25.3778	25.4989	25.6201	25.7414	25.8629	25.9845	26.1063	26.2282	26.3502	26.4723	26.5946	26.717

286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310
16.1355	16.1282	16.1206	16.1128	16.1049	16.0967	16.0884	16.0799	16.0712	16.0624	16.0533	16.0441	16.0347	16.0252	16.0155	16.0056	15.9955	15.9853	15.9749	15.9643	15.9536	15.9427	15.9317	15.9205	15.9091
12.672	12.6804	12.6887	12.6969	12.7052	12.7134	12.7215	12.7297	12.7378	12.7458	12.7539	12.7619	12.7698	12.7777	12.7856	12.7935	12.8013	12.8091	12.8168	12.8245	12.8322	12.8399	12.8475	12.8551	12.8626
9.92939	9.916	9.90249	9.88885	9.8751	9.86123	9.84724	9.83314	9.81892	9.8046	9.79016	9.77562	9.76097	9.74622	9.73136	9.7164	9.70134	9.68619	9.67093	9.65558	9.64014	9.6246	9.60898	9.59326	9.57746
7.2384	7.2448	7.25117	7.25751	7.26383	7.27012	7.27638	7.28262	7.28884	7.29502	7.30118	7.30732	7.31343	7.31951	7.32557	7.3316	7.33761	7.34359	7.34955	7.35548	7.36139	7.36727	7.37313	7.37896	7.38476
8.65128	8.64758	8.64382	8.63999	8.63609	8.63212	8.62808	8.62398	8.61981	8.61557	8.61127	8.6069	8.60248	8.59798	8.59343	8.58881	8.58414	8.5794	8.5746	8.56975	8.56483	8.55986	8.55483	8.54974	8.5446
7.22182	7.22555	7.22925	7.23294	7.23662	7.24027	7.24391	7.24753	7.25114	7.25472	7.2583	7.26185	7.26539	7.26891	7.27241	7.2759	7.27938	7.28283	7.28627	7.2897	7.2931	7.2965	7.29987	7.30323	7.30658
39.0569	39.2329	39.4087	39.5844	39.76	39.9354	40.1106	40.2857	40.4606	40.6353	40.8099	40.9842	41.1585	41.3325	41.5063	41.68	41.8535	42.0268	42.1999	42.3728	42.5455	42.718	42.8903	43.0624	43.2343
26.8395	26.9622	27.0849	27.2078	27.3309	27.454	27.5773	27.7007	27.8242	27.9479	28.0716	28.1955	28.3196	28.4437	28.5679	28.6923	28.8168	28.9414	29.0662	29.191	29.316	29.4411	29.5663	29.6916	29.817

311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335
15.8976	15.886	15.8741	15.8622	15.8501	15.8378	15.8254	15.8129	15.8002	15.7873	15.774	15.7612	15.748	15.7346	15.7211	15.7074	15.6937	15.6797	15.6657	15.6515	15.6372	15.6228	15.6083	15.5936	15.5788
12.8701	12.8776	12.8851	12.8925	12.8999	12.9072	12.9145	12.9218	12.9291	12.9363	12.944	12.9507	12.9578	12.9649	12.9719	12.979	12.986	12.9929	12.9999	13.0068	13.0136	13.0205	13.0273	13.0341	13.0408
9.56157	9.54559	9.52953	9.51339	9.49717	9.48087	9.46449	9.44803	9.4315	9.4149	9.3982	9.38147	9.36466	9.34777	9.33082	9.3138	9.29671	9.27957	9.26236	9.24509	9.22776	9.21038	9.19293	9.17544	9.15789
7.39055	7.3963	7.40204	7.40774	7.41343	7.41909	7.42472	7.43033	7.43591	7.44148	7.447	7.45253	7.45802	7.46348	7.46892	7.47434	7.47973	7.4851	7.49045	7.49577	7.50107	7.50635	7.5116	7.51683	7.52204
8.5394	8.53415	8.52884	8.52348	8.51806	8.51259	8.50708	8.5015	8.49588	8.49021	8.4845	8.47872	8.4729	8.46703	8.46111	8.45515	8.44914	8.44308	8.43698	8.43084	8.42465	8.41842	8.41214	8.40582	8.39946
7.30991	7.31322	7.31652	7.3198	7.32307	7.32632	7.32955	7.33277	7.33598	7.33917	7.3423	7.3455	7.34865	7.35178	7.35489	7.358	7.36108	7.36415	7.36721	7.37025	7.37328	7.37629	7.37929	7.38227	7.38524
43.406	43.5775	43.7488	43.9198	44.0907	44.2613	44.4317	44.6019	44.7719	44.9416	45.111	45.2804	45.4495	45.6183	45.7869	45.9552	46.1234	46.2912	46.4589	46.6263	46.7934	46.9604	47.127	47.2934	47.4596
29.9426	30.0682	30.194	30.3199	30.4459	30.572	30.6982	30.8246	30.951	31.0776	31.204	31.331	31.4579	31.5849	31.712	31.8392	31.9665	32.094	32.2215	32.3491	32.4769	32.6047	32.7327	32.8607	32.9889

261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285
16.2544	16.2523	16.2499	16.2472	16.2444	16.2413	16.238	16.2345	16.2308	16.2268	16.2227	16.2183	16.2137	16.2089	16.2039	16.1987	16.1933	16.1877	16.1818	16.1758	16.1696	16.1632	16.1566	16.1497	16.1427
12.4514	12.4606	12.4699	12.4791	12.4883	12.4974	12.5065	12.5155	12.5245	12.5335	12.5424	12.5513	12.5602	12.569	12.5778	12.5866	12.5953	12.6039	12.6126	12.6212	12.6297	12.6383	12.6468	12.6552	12.6636
10.2194	10.2096	10.1997	10.1896	10.1793	10.1689	10.1583	10.1476	10.1367	10.1256	10.1144	10.1031	10.0916	10.0799	10.0681	10.0562	10.0441	10.0319	10.0196	10.0071	9.99446	9.9817	9.96882	9.9558	9.94266
7.06976	7.07684	7.08388	7.0909	7.09789	7.10486	7.11179	7.1187	7.12558	7.13244	7.13926	7.14606	7.15283	7.15958	7.16629	7.17298	7.17965	7.18628	7.19289	7.19947	7.20603	7.21256	7.21906	7.22553	7.23198
8.71875	8.71704	8.71525	8.71336	8.71139	8.70933	8.70719	8.70496	8.70265	8.70026	8.69778	8.69522	8.69259	8.68987	8.68707	8.6842	8.68124	8.67821	8.67511	8.67192	8.66867	8.66533	8.66193	8.65845	8.6549
7.12291	7.12709	7.13125	7.13539	7.13951	7.14361	7.1477	7.15176	7.15581	7.15984	7.16385	7.16784	7.17181	7.17577	7.1797	7.18362	7.18752	7.1914	7.19527	7.19911	7.20294	7.20675	7.21055	7.21432	7.21808
34.6166	34.7954	34.9741	35.1527	35.3312	35.5097	35.6881	35.8664	36.0446	36.2227	36.4007	36.5786	36.7564	36.9341	37.1117	37.2891	37.4665	37.6437	37.8208	37.9978	38.1747	38.3514	38.528	38.7044	38.8807
23.8159	23.9352	24.0547	24.1743	24.294	24.4139	24.5339	24.654	24.7743	24.8947	25.0153	25.136	25.2568	25.3778	25.4989	25.6201	25.7414	25.8629	25.9845	26.1063	26.2282	26.3502	26.4723	26.5946	26.717

Time (Month)	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305
GPP : Intervention	16.136	16.1282	16.1206	16.1128	16.1049	16.0967	16.0884	16.0799	16.0712	16.0624	16.0533	16.0441	16.0347	16.0252	16.0155	16.0056	15.9955	15.9853	15.9749	15.9643
GPP : Non-Intervention	12.672	12.6804	12.6887	12.6969	12.7052	12.7134	12.7215	12.7297	12.7378	12.7458	12.7539	12.7619	12.7698	12.7777	12.7856	12.7935	12.8013	12.8091	12.8168	12.8245
Consumption : Intervention	9.9294	9.916	9.90249	9.88885	9.8751	9.86123	9.84724	9.83314	9.81892	9.8046	9.79016	9.77562	9.76097	9.74622	9.73136	9.7164	9.70134	9.68619	9.67093	9.65558
Consumption : Non-Intervention	7.2384	7.2448	7.25117	7.25751	7.26383	7.27012	7.27638	7.28262	7.28884	7.29502	7.30118	7.30732	7.31343	7.31951	7.32557	7.3316	7.33761	7.34359	7.34955	7.35548
Waste : Intervention	8.6513	8.64758	8.64382	8.63999	8.63609	8.63212	8.62808	8.62398	8.61981	8.61557	8.61127	8.6069	8.60248	8.59798	8.59343	8.58881	8.58414	8.5794	8.5746	8.56975
Waste : Non-Intervention	7.2218	7.22555	7.22925	7.23294	7.23662	7.24027	7.24391	7.24753	7.25114	7.25472	7.2583	7.26185	7.26539	7.26891	7.27241	7.2759	7.27938	7.28283	7.28627	7.2897
Threat to Ecosystem : Intervention	39.057	39.2329	39.4087	39.5844	39.76	39.9354	40.1106	40.2857	40.4606	40.6353	40.8099	40.9842	41.1585	41.3325	41.5063	41.68	41.8535	42.0268	42.1999	42.3728
Threat to Ecosystem : Non-Intervention	26.84	26.9622	27.0849	27.2078	27.3309	27.454	27.5773	27.7007	27.8242	27.9479	28.0716	28.1955	28.3196	28.4437	28.5679	28.6923	28.8168	28.9414	29.0662	29.191

306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330
15.9536	15.9427	15.9317	15.9205	15.9091	15.8976	15.886	15.8741	15.8622	15.8501	15.8378	15.8254	15.8129	15.8002	15.7873	15.774	15.7612	15.748	15.7346	15.7211	15.7074	15.6937	15.6797	15.6657	15.6515
12.8322	12.8399	12.8475	12.8551	12.8626	12.8701	12.8776	12.8851	12.8925	12.8999	12.9072	12.9145	12.9218	12.9291	12.9363	12.944	12.9507	12.9578	12.9649	12.9719	12.979	12.986	12.9929	12.9999	13.0068
9.64014	9.6246	9.60898	9.59326	9.57746	9.56157	9.54559	9.52953	9.51339	9.49717	9.48087	9.46449	9.44803	9.4315	9.4149	9.3982	9.38147	9.36466	9.34777	9.33082	9.3138	9.29671	9.27957	9.26236	9.24509
7.36139	7.36727	7.37313	7.37896	7.38476	7.39055	7.3963	7.40204	7.40774	7.41343	7.41909	7.42472	7.43033	7.43591	7.44148	7.447	7.45253	7.45802	7.46348	7.46892	7.47434	7.47973	7.4851	7.49045	7.49577
8.56483	8.55986	8.55483	8.54974	8.5446	8.5394	8.53415	8.52884	8.52348	8.51806	8.51259	8.50708	8.5015	8.49588	8.49021	8.4845	8.47872	8.4729	8.46703	8.46111	8.45515	8.44914	8.44308	8.43698	8.43084
7.2931	7.2965	7.29987	7.30323	7.30658	7.30991	7.31322	7.31652	7.3198	7.32307	7.32632	7.32955	7.33277	7.33598	7.33917	7.3423	7.3455	7.34865	7.35178	7.35489	7.358	7.36108	7.36415	7.36721	7.37025
42.5455	42.718	42.8903	43.0624	43.2343	43.406	43.5775	43.7488	43.9198	44.0907	44.2613	44.4317	44.6019	44.7719	44.9416	45.111	45.2804	45.4495	45.6183	45.7869	45.9552	46.1234	46.2912	46.4589	46.6263
29.316	29.4411	29.5663	29.6916	29.817	29.9426	30.0682	30.194	30.3199	30.4459	30.572	30.6982	30.8246	30.951	31.0776	31.204	31.331	31.4579	31.5849	31.712	31.8392	31.9665	32.094	32.2215	32.3491

331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355
15.6372	15.6228	15.6083	15.5936	15.5788	15.5639	15.5489	15.5338	15.5185	15.5031	15.4877	15.4721	15.4564	15.4406	15.4247	15.4087	15.3925	15.3763	15.36	15.3436	15.327	15.3104	15.2937	15.2769	15.26
13.0136	13.0205	13.0273	13.0341	13.0408	13.0476	13.0542	13.0609	13.0675	13.0741	13.0807	13.0872	13.0937	13.1002	13.1067	13.1131	13.1195	13.1258	13.1322	13.1385	13.1448	13.151	13.1572	13.1634	13.1696
9.22776	9.21038	[illegible]	[illegible]	9.15789	9.14028	9.12262	9.10491	9.08716	9.06935	9.0515	9.0336	9.01566	8.99767	8.97964	8.96157	8.94346	8.92531	8.90712	8.8889	8.87064	8.85234	8.83401	8.81565	8.79726
7.50107	7.50635	7.5116	7.51683	7.52204	7.52722	7.53238	7.53752	7.54263	7.54773	7.55279	7.55784	7.56286	7.56786	7.57284	7.5778	7.58273	7.58764	7.59253	7.5974	7.60224	7.60706	7.61187	7.61664	7.6214
8.42465	8.41842	8.41214	8.40582	8.39946	8.39305	8.38661	8.38012	8.3736	8.36703	8.36043	8.35378	8.3471	8.34038	8.33362	8.32683	8.32	8.31314	8.30624	8.2993	8.29233	8.28533	8.27829	8.27122	8.26411
7.37328	7.37629	7.37929	7.38227	7.38524	7.3882	7.39114	7.39407	7.39698	7.39988	7.40277	7.40564	7.4085	7.41134	7.41417	7.41699	7.41979	7.42258	7.42536	7.42812	7.43087	7.4336	7.43633	7.43904	7.44173
46.7934	46.9604	47.127	47.2934	47.4596	47.6255	47.7912	47.9566	48.1217	48.2866	48.4512	48.6156	48.7797	48.9436	49.1072	49.2705	49.4335	49.5963	49.7589	49.9211	50.0831	50.2448	50.4062	50.5674	50.7283
32.4769	32.6047	32.7327	32.8607	32.9889	33.1172	33.2455	33.374	33.5026	33.6312	33.76	33.8889	34.0179	34.1469	34.2761	34.4054	34.5347	34.6642	34.7938	34.9234	35.0532	35.183	35.313	35.443	35.5732

356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380
15.243	15.2259	15.2087	15.1914	15.1741	15.1566	15.1391	15.1215	15.1038	15.086	15.0681	15.0502	15.0322	15.0141	14.9959	14.9777	14.9594	14.941	14.9225	14.904	14.8854	14.8667	14.848	14.8292	14.8104
13.1757	13.1818	13.1879	13.1939	13.1999	13.2059	13.2119	13.2178	13.2237	13.2296	13.2355	13.2413	13.2471	13.2529	13.2586	13.2643	13.27	13.2757	13.2813	13.2869	13.2925	13.298	13.3036	13.3091	13.3146
8.77883	8.76038	8.7419	8.72339	8.70485	8.68629	8.6677	8.64909	8.63046	8.6118	8.59313	8.57443	8.55571	8.53698	8.51823	8.49946	8.48068	8.46189	8.44308	8.42425	8.40542	8.38657	8.36771	8.34885	8.32997
7.62613	7.63085	7.63554	7.64021	7.64486	7.64949	7.65409	7.65867	7.66324	7.66778	7.6723	7.6768	7.68128	7.68574	7.69017	7.69459	7.69898	7.70336	7.70771	7.71205	7.71636	7.72065	7.72493	7.72918	7.73341
8.25698	8.24981	8.24261	8.23538	8.22812	8.22083	8.21351	8.20616	8.19879	8.19138	8.18395	8.17649	8.169	8.16148	8.15394	8.14638	8.13879	8.13117	8.12353	8.11586	8.10817	8.10046	8.09272	8.08496	8.07718
7.44442	7.44709	7.44974	7.45239	7.45502	7.45764	7.46024	7.46284	7.46542	7.46798	7.47054	7.47308	7.47561	7.47813	7.48063	7.48313	7.48561	7.48807	7.49053	7.49297	7.49541	7.49782	7.50023	7.50263	7.50501
50.8889	51.0492	51.2093	51.369	51.5285	51.6877	51.8467	52.0053	52.1637	52.3218	52.4795	52.6371	52.7943	52.9512	53.1079	53.2642	53.4203	53.576	53.7315	53.8867	54.0416	54.1962	54.3505	54.5046	54.6583
35.7034	35.8337	35.9642	36.0947	36.2253	36.356	36.4868	36.6177	36.7486	36.8797	37.0108	37.1421	37.2734	37.4048	37.5364	37.668	37.7996	37.9314	38.0633	38.1952	38.3273	38.4594	38.5916	38.7239	38.8562

381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405
14.7914	14.7724	14.7534	14.7343	14.7151	14.6959	14.6766	14.6573	14.6379	14.6185	14.599	14.5794	14.5598	14.5402	14.5205	14.5008	14.481	14.4611	14.4413	14.4213	14.4014	14.3814	14.3613	14.3412	14.3211
13.32	13.3254	13.3308	13.3362	13.3416	13.3469	13.3522	13.3574	13.3627	13.3679	13.3731	13.3783	13.3834	13.3885	13.3936	13.3987	13.4038	13.4088	13.4138	13.4188	13.4237	13.4286	13.4335	13.4384	13.4433
8.31109	8.2922	8.2733	8.2544	8.2355	8.21659	8.19767	8.17876	8.15984	8.14092	8.122	8.10308	8.08416	8.06525	8.04633	8.02742	8.00852	7.98962	7.97072	7.95183	7.93294	7.91407	7.8952	7.87633	7.85748
7.73762	7.74181	7.74599	7.75014	7.75427	7.75838	7.76247	7.76655	7.7706	7.77463	7.77865	7.78264	7.78662	7.79057	7.79451	7.79843	7.80232	7.8062	7.81006	7.81391	7.81773	7.82153	7.82532	7.82908	7.83283
8.06938	8.06155	8.05371	8.04584	8.03795	8.03005	8.02212	8.01417	8.00621	7.99822	7.99022	7.9822	7.97416	7.9661	7.95803	7.94994	7.94183	7.93371	7.92557	7.91742	7.90925	7.90107	7.89287	7.88466	7.87643
7.50738	7.50974	7.51209	7.51443	7.51675	7.51907	7.52137	7.52366	7.52594	7.52821	7.53046	7.53271	7.53494	7.53716	7.53937	7.54157	7.54376	7.54594	7.5481	7.55026	7.55241	7.55454	7.55666	7.55877	7.56088
54.8117	54.9648	55.1177	55.2702	55.4224	55.5744	55.726	55.8773	56.0284	56.1791	56.3296	56.4797	56.6295	56.7791	56.9283	57.0772	57.2259	57.3742	57.5222	57.6699	57.8174	57.9645	58.1113	58.2578	58.404
38.9887	39.1212	39.2539	39.3866	39.5194	39.6522	39.7852	39.9182	40.0513	40.1845	40.3178	40.4512	40.5846	40.7181	40.8517	40.9854	41.1192	41.253	41.3869	41.5209	41.6549	41.7891	41.9233	42.0576	42.1919

Time (Month)	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425
GPP : Intervention	14.301	14.2808	14.2605	14.2403	14.22	14.1996	14.1793	14.1589	14.1384	14.118	14.0975	14.077	14.0564	14.0359	14.0153	13.9946	13.974	13.9533	13.9327	13.9119
GPP : Non-Intervention	13.448	13.4529	13.4577	13.4624	13.4672	13.4719	13.4766	13.4812	13.4859	13.4905	13.4951	13.4997	13.5042	13.5088	13.5133	13.5177	13.5222	13.5266	13.5311	13.5355
Consumption : Intervention	7.8386	7.81981	7.80098	7.78217	7.76337	7.74459	7.72581	7.70705	7.68831	7.66957	7.65086	7.63216	7.61347	7.59481	7.57615	7.55752	7.53891	7.52031	7.50173	7.48318
Consumption : Non-Intervention	7.8366	7.84027	7.84396	7.84764	7.85129	7.85493	7.85855	7.86215	7.86573	7.8693	7.87285	7.87638	7.87989	7.88338	7.88686	7.89032	7.89376	7.89718	7.90059	7.90398
Waste : Intervention	7.8682	7.85994	7.85168	7.8434	7.83511	7.82681	7.81849	7.81017	7.80183	7.79348	7.78512	7.77675	7.76838	7.75999	7.75159	7.74318	7.73477	7.72634	7.71791	7.70947
Waste : Non-Intervention	7.563	7.56505	7.56712	7.56917	7.57122	7.57326	7.57529	7.5773	7.57931	7.58131	7.58329	7.58527	7.58723	7.58919	7.59114	7.59307	7.595	7.59691	7.59882	7.60071
Threat to Ecosystem : Intervention	58.55	58.6955	58.8407	58.9857	59.1304	59.2748	59.4188	59.5626	59.706	59.8492	59.992	60.1345	60.2768	60.4187	60.5603	60.7016	60.8426	60.9833	61.1237	61.2637
Threat to Ecosystem : Non-Intervention	42.326	42.4609	42.5955	42.7301	42.8649	42.9997	43.1345	43.2695	43.4045	43.5396	43.6748	43.81	43.9453	44.0807	44.2161	44.3517	44.4872	44.6229	44.7586	44.8944

426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450
13.8912	13.8705	13.8497	13.8289	13.8081	13.7873	13.7664	13.7456	13.7247	13.7039	13.683	13.6621	13.6411	13.6202	13.5993	13.5783	13.5574	13.5364	13.5154	13.4945	13.4735	13.4525	13.4315	13.4105	13.3895
13.5398	13.5442	13.5485	13.5528	13.5571	13.5614	13.5656	13.5698	13.574	13.5782	13.5824	13.5865	13.5906	13.5947	13.5988	13.6028	13.6068	13.6109	13.6148	13.6188	13.6228	13.6267	13.6306	13.6345	13.6384
7.46464	7.44612	7.42763	7.40916	7.3907	7.37227	7.35387	7.33548	7.31712	7.29879	7.28048	7.26219	7.24393	7.22569	7.20748	7.1893	7.17114	7.15301	7.13491	7.11683	7.09879	7.08077	7.06278	7.04482	7.02689
7.90735	7.9107	7.91404	7.91736	7.92066	7.92395	7.92721	7.93047	7.9337	7.93692	7.94012	7.9433	7.94647	7.94962	7.95276	7.95588	7.95898	7.96207	7.96514	7.96819	7.97123	7.97425	7.97725	7.98024	7.98321
7.70102	7.69256	7.6841	7.67563	7.66715	7.65866	7.65017	7.64167	7.63317	7.62466	7.61615	7.60763	7.5991	7.59057	7.58204	7.5735	7.56496	7.55641	7.54786	7.53931	7.53075	7.52219	7.51363	7.50506	7.49649
7.6026	7.60447	7.60634	7.60819	7.61004	7.61188	7.6137	7.61552	7.61733	7.61913	7.62092	7.6227	7.62447	7.62623	7.62798	7.62972	7.63145	7.63318	7.63489	7.6366	7.63829	7.63998	7.64166	7.64333	7.64499
61.4035	61.543	61.6821	61.821	61.9595	62.0978	62.2357	62.3734	62.5107	62.6477	62.7844	62.9208	63.0569	63.1927	63.3282	63.4634	63.5983	63.7329	63.8672	64.0011	64.1348	64.2682	64.4012	64.534	64.6665
45.0303	45.1662	45.3022	45.4382	45.5744	45.7106	45.8468	45.9831	46.1195	46.256	46.3925	46.5291	46.6657	46.8024	46.9392	47.076	47.2129	47.3499	47.4869	47.624	47.7611	47.8983	48.0356	48.1729	48.3103

451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475
13.3685	13.3475	13.3265	13.3055	13.2845	13.2635	13.2425	13.2215	13.2005	13.1795	13.1585	13.1375	13.1165	13.0955	13.0745	13.0535	13.0326	13.0116	12.9907	12.9697	12.9488	12.9279	12.9069	12.886	12.8652
13.6422	13.646	13.6498	13.6536	13.6574	13.6611	13.6649	13.6686	13.6723	13.6759	13.6796	13.6832	13.6868	13.6904	13.694	13.6975	13.7011	13.7046	13.7081	13.7116	13.715	13.7185	13.7219	13.7253	13.7287
7.00899	6.99112	6.97328	6.95547	6.93769	6.91994	6.90222	6.88454	6.86689	6.84927	6.83168	6.81413	6.79661	6.77912	6.76167	6.74425	6.72687	6.70951	6.6922	6.67492	6.65767	6.64046	6.62329	6.60615	6.58905
7.98617	7.98911	7.99204	7.99495	7.99784	8.00072	8.00359	8.00643	8.00927	8.01208	8.01488	8.01767	8.02044	8.0232	8.02594	8.02867	8.03138	8.03407	8.03676	8.03942	8.04207	8.04471	8.04733	8.04994	8.05253
7.48793	7.47935	7.47078	7.46221	7.45363	7.44505	7.43647	7.4279	7.41932	7.41074	7.40216	7.39358	7.385	7.37642	7.36784	7.35926	7.35068	7.34211	7.33353	7.32496	7.31639	7.30782	7.29925	7.29068	7.28212
7.64664	7.64828	7.64992	7.65154	7.65316	7.65477	7.65637	7.65796	7.65954	7.66111	7.66268	7.66423	7.66578	7.66732	7.66885	7.67037	7.67188	7.67339	7.67489	7.67638	7.67786	7.67933	7.6808	7.68225	7.6837
64.7986	64.9305	65.062	65.1933	65.3242	65.4549	65.5852	65.7153	65.845	65.9745	66.1036	66.2325	66.3611	66.4893	66.6173	66.7449	66.8723	66.9994	67.1261	67.2526	67.3788	67.5047	67.6302	67.7555	67.8805
48.4478	48.5853	48.7228	48.8605	48.9981	49.1359	49.2737	49.4115	49.5494	49.6874	49.8254	49.9635	50.1017	50.2398	50.3781	50.5164	50.6548	50.7932	50.9316	51.0702	51.2087	51.3474	51.4861	51.6248	51.7636

476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500
12.8443	12.8234	12.8025	12.7817	12.7609	12.74	12.7192	12.6984	12.6777	12.6569	12.6362	12.6154	12.5947	12.574	12.5534	12.5327	12.5121	12.4914	12.4708	12.4503	12.4297	12.4091	12.3886	12.3681	12.3476
13.7321	13.7354	13.7387	13.7421	13.7454	13.7486	13.7519	13.7551	13.7584	13.7616	13.7648	13.7679	13.7711	13.7742	13.7774	13.7805	13.7835	13.7866	13.7897	13.7927	13.7957	13.7987	13.8017	13.8047	13.8076
6.57198	6.55495	6.53795	6.521	6.50408	6.48719	6.47035	6.45354	6.43677	6.42004	6.40334	6.38669	6.37007	6.35349	6.33695	6.32045	6.30398	6.28756	6.27117	6.25483	6.23852	6.22226	6.20603	6.18984	6.17369
8.05511	8.05768	8.06023	8.06276	8.06528	8.06779	8.07028	8.07276	8.07523	8.07768	8.08011	8.08254	8.08495	8.08734	8.08972	8.09209	8.09444	8.09678	8.09911	8.10142	8.10372	8.10601	8.10828	8.11054	8.11279
7.27356	7.265	7.25644	7.24789	7.23934	7.23079	7.22225	7.21371	7.20517	7.19664	7.18811	7.17959	7.17107	7.16255	7.15404	7.14553	7.13703	7.12853	7.12004	7.11155	7.10307	7.0946	7.08613	7.07766	7.0692
7.68514	7.68657	7.688	7.68941	7.69082	7.69222	7.69362	7.695	7.69638	7.69775	7.69911	7.70047	7.70181	7.70315	7.70448	7.70581	7.70712	7.70843	7.70973	7.71103	7.71231	7.71359	7.71487	7.71613	7.71739
68.0052	68.1297	68.2538	68.3776	68.5012	68.6244	68.7474	68.87	68.9924	69.1145	69.2363	69.3578	69.479	69.5999	69.7206	69.8409	69.961	70.0808	70.2003	70.3195	70.4385	70.5571	70.6755	70.7936	70.9114
51.9024	52.0413	52.1803	52.3193	52.4583	52.5974	52.7365	52.8757	53.015	53.1543	53.2936	53.433	53.5725	53.712	53.8515	53.9911	54.1308	54.2705	54.4102	54.55	54.6898	54.8297	54.9696	55.1096	55.2496

501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525
12.3272	12.3068	12.2863	12.2659	12.2456	12.2252	12.2049	12.1846	12.1644	12.1441	12.1239	12.1037	12.0835	12.0634	12.043	12.0232	12.0031	11.9831	11.9631	11.9431	11.9231	11.9032	11.8833	11.8635	11.8436
13.8106	13.8135	13.8164	13.8193	13.8221	13.825	13.8278	13.8307	13.8335	13.8363	13.839	13.8418	13.8445	13.8473	13.85	13.8527	13.8553	13.858	13.8607	13.8633	13.8659	13.8685	13.8711	13.8737	13.8762
6.15759	6.14152	6.12549	6.10951	6.09356	6.07765	6.06179	6.04597	6.03018	6.01444	5.99874	5.98308	5.96746	5.95188	5.9363	5.92085	5.9054	5.88998	5.87461	5.85928	5.84399	5.82875	5.81354	5.79838	5.78326
8.11502	8.11724	8.11945	8.12164	8.12383	8.12599	8.12815	8.13029	8.13242	8.13454	8.13664	8.13873	8.14081	8.14288	8.1449	8.14697	8.149	8.15102	8.15302	8.15501	8.15699	8.15896	8.16091	8.16285	8.16478
7.06075	7.05231	7.04387	7.03543	7.027	7.01858	7.01017	7.00176	6.99336	6.98497	6.97658	6.9682	6.95983	6.95147	6.9431	6.93476	6.92642	6.91809	6.90976	6.90145	6.89314	6.88484	6.87655	6.86826	6.85999
7.71864	7.71988	7.72112	7.72235	7.72357	7.72478	7.72599	7.72719	7.72838	7.72957	7.73075	7.73192	7.73309	7.73425	7.7354	7.73654	7.73768	7.73881	7.73994	7.74106	7.74217	7.74327	7.74437	7.74546	7.74655
71.0289	71.1461	71.2631	71.3798	71.4962	71.6123	71.7281	71.8437	71.959	72.074	72.1887	72.3032	72.4174	72.5313	72.645	72.7583	72.8714	72.9842	73.0968	73.2091	73.3211	73.4328	73.5443	73.6555	73.7664
55.3896	55.5298	55.6699	55.8101	55.9503	56.0906	56.231	56.3713	56.5117	56.6522	56.7927	56.9333	57.0738	57.2145	57.355	57.4959	57.6366	57.7774	57.9183	58.0591	58.2001	58.341	58.482	58.6231	58.7641

Time (Month)	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545
GPP : Intervention	11.824	11.804	11.7843	11.7646	11.7449	11.7252	11.7056	11.686	11.6664	11.6469	11.6274	11.6079	11.5885	11.5691	11.5497	11.5304	11.5111	11.4918	11.4726	11.4534
GPP : Non-Intervention	13.879	13.8813	13.8838	13.8863	13.8888	13.8913	13.8937	13.8962	13.8986	13.901	13.9034	13.9058	13.9081	13.9105	13.9128	13.9151	13.9175	13.9198	13.922	13.9243
Consumption : Intervention	5.7682	5.75314	5.73815	5.7232	5.70828	5.69342	5.67859	5.6638	5.64906	5.63436	5.6197	5.60508	5.59051	5.57598	5.56149	5.54704	5.53264	5.51827	5.50395	5.48967
Consumption : Non-Intervention	8.1667	8.16861	8.1705	8.17239	8.17426	8.17612	8.17797	8.1798	8.18163	8.18344	8.18524	8.18703	8.18881	8.19057	8.19233	8.19407	8.19581	8.19753	8.19924	8.20094
Waste : Intervention	6.8517	6.84346	6.83521	6.82697	6.81874	6.81052	6.80231	6.79411	6.78591	6.77773	6.76956	6.76139	6.75324	6.74509	6.73696	6.72883	6.72071	6.71261	6.70451	6.69643
Waste : Non-Intervention	7.7476	7.7487	7.74977	7.75083	7.75188	7.75293	7.75397	7.755	7.75603	7.75705	7.75806	7.75907	7.76008	7.76107	7.76206	7.76305	7.76403	7.765	7.76596	7.76692
Threat to Ecosystem : Intervention	73.877	73.9875	74.0976	74.2075	74.3171	74.4264	74.5355	74.6443	74.7529	74.8612	74.9692	75.077	75.1845	75.2917	75.3987	75.5055	75.6119	75.7182	75.8241	75.9298
Threat to Ecosystem : Non-Intervention	58.905	59.0464	59.1876	59.3289	59.4701	59.6115	59.7528	59.8942	60.0356	60.1771	60.3186	60.4601	60.6017	60.7433	60.885	61.0267	61.1684	61.3102	61.452	61.5938

545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569
11.4534	11.4342	11.4151	11.396	11.3769	11.3579	11.3389	11.3199	11.301	11.2821	11.2632	11.2444	11.2256	11.2069	11.1882	11.1695	11.1509	11.1323	11.1137	11.0951	11.0767	11.0582	11.0398	11.0214	11.003
13.9243	13.9266	13.9288	13.931	13.9332	13.9354	13.9376	13.9398	13.942	13.9441	13.9462	13.9484	13.9505	13.9526	13.9546	13.9567	13.9588	13.9608	13.9628	13.9648	13.9668	13.9688	13.9708	13.9728	13.9747
5.48967	5.47544	5.46124	5.44709	5.43298	5.41891	5.40489	5.3909	5.37696	5.36306	5.34921	5.33539	5.32162	5.30789	5.2942	5.28056	5.26695	5.25339	5.23987	5.22639	5.21295	5.19956	5.1862	5.17289	5.15962
8.20094	8.20262	8.2043	8.20597	8.20762	8.20926	8.2109	8.21252	8.21413	8.21573	8.21732	8.2189	8.22047	8.22202	8.22357	8.22511	8.22663	8.22815	8.22966	8.23115	8.23263	8.23411	8.23557	8.23703	8.23847
6.69643	6.68835	6.68029	6.67224	6.66419	6.65616	6.64814	6.64013	6.63213	6.62414	6.61616	6.60819	6.60024	6.59229	6.58436	6.57643	6.56852	6.56062	6.55273	6.54486	6.53699	6.52914	6.52129	6.51346	6.50564
7.76692	7.76788	7.76883	7.76977	7.7707	7.77163	7.77256	7.77348	7.77439	7.7753	7.7762	7.77709	7.77798	7.77887	7.77975	7.78062	7.78149	7.78235	7.7832	7.78405	7.7849	7.78574	7.78657	7.7874	7.78822
75.9298	76.0353	76.1405	76.2454	76.3501	76.4546	76.5587	76.6627	76.7664	76.8698	76.973	77.0759	77.1786	77.2811	77.3833	77.4852	77.5869	77.6884	77.7896	77.8906	77.9913	78.0918	78.1921	78.2921	78.3919
61.5938	61.7356	61.8775	62.0195	62.1614	62.3034	62.4455	62.5876	62.7297	62.8718	63.014	63.1562	63.2984	63.4407	63.583	63.7253	63.8677	64.0101	64.1525	64.295	64.4375	64.58	64.7225	64.8651	65.0077

570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594
10.9847	10.9665	10.9482	10.93	10.9119	10.8937	10.8757	10.8576	10.8396	10.8216	10.8037	10.7858	10.768	10.7502	10.732	10.715	10.6969	10.6793	10.6617	10.6441	10.6265	10.609	10.5916	10.5741	10.5568
13.9767	13.9786	13.9805	13.9824	13.9843	13.9862	13.988	13.9899	13.9917	13.9936	13.9954	13.9972	13.999	14.0008	14.003	14.004	14.006	14.0078	14.0095	14.0112	14.0129	14.0146	14.0162	14.0179	14.0196
5.1464	5.13321	5.12007	5.10696	5.0939	5.08088	5.0679	5.05497	5.04207	5.02921	5.0164	5.00363	4.9909	4.97821	4.9656	4.953	4.94038	4.92786	4.91537	4.90293	4.89052	4.87816	4.86584	4.85355	4.84131
8.2399	8.24133	8.24274	8.24414	8.24554	8.24692	8.24829	8.24966	8.25101	8.25236	8.25369	8.25501	8.25633	8.25764	8.2589	8.2602	8.26149	8.26276	8.26402	8.26527	8.26651	8.26774	8.26896	8.27017	8.27137
6.49784	6.49004	6.48226	6.47448	6.46673	6.45898	6.45124	6.44352	6.43581	6.42811	6.42042	6.41275	6.40509	6.39744	6.3898	6.3822	6.37456	6.36696	6.35937	6.3518	6.34424	6.33669	6.32915	6.32163	6.31412
7.78904	7.78985	7.79066	7.79146	7.79226	7.79305	7.79383	7.79461	7.79539	7.79616	7.79692	7.79768	7.79844	7.79918	7.7999	7.8007	7.8014	7.80213	7.80285	7.80357	7.80429	7.80499	7.8057	7.8064	7.80709
78.4914	78.5907	78.6897	78.7886	78.8871	78.9855	79.0836	79.1815	79.2791	79.3765	79.4737	79.5706	79.6673	79.7638	79.86	79.956	80.0518	80.1474	80.2427	80.3379	80.4327	80.5274	80.6218	80.716	80.81
65.1504	65.293	65.4357	65.5785	65.7212	65.864	66.0069	66.1497	66.2926	66.4355	66.5784	66.7214	66.8644	67.0074	67.15	67.294	67.4366	67.5797	67.7229	67.8661	68.0093	68.1525	68.2958	68.439	68.5824

595	596	597	598	599	600
10.5394	10.5221	10.5048	10.4876	10.4704	10.4533
14.0212	14.0228	14.0245	14.0261	14.0277	14.0292
4.82911	4.81695	4.80483	4.79275	4.7807	4.7687
8.27256	8.27375	8.27492	8.27609	8.27724	8.27839
6.30662	6.29913	6.29166	6.2842	6.27676	6.26932
7.80778	7.80847	7.80914	7.80982	7.81049	7.81115
80.9037	80.9973	81.0906	81.1837	81.2766	81.3692
68.7257	68.8691	69.0124	69.1559	69.2993	69.4427

VITA

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PROFESSIONAL SUMMARY

A career military officer who served 24 years of active duty at four overseas and eight stateside duty stations, including command and several Pentagon planning and policy positions. Has extensive knowledge of and expertise in strategic planning, policy development and operationalizing international relations and diplomacy, as well as coordinating Joint, Interagency, and Multinational operations. Senior Defense Official for the US Ambassador to New Zealand and heads of US agencies on national security matters. Lead diplomat for a 25-year-old US policy adjustment regarding defense interaction with New Zealand. Developed and established the Navy's Foreign Area Officer program and served as a senior leader of the community until retirement at the rank of Captain. Possesses knowledge of planning, implementation, and operation of Department of Defense intelligence systems.

TEACHING EXPERIENCE

- Adjunct Professor, Old Dominion University, Department of Political Science and Geography teaching International Relations (2018-2019)
- Strategic Communications Consultant/Instructor, Fort Bragg, NC as subject matter expert in professional communications, briefings and negotiations for international and domestic executive decision makers (2013-2016)

CONFERENCE PRESENTATIONS

- The International Studies Association's 59th Annual Convention in San Francisco (April 2018)
  - *Marine Debris and Human Security: Hidden Threats in the Food Chain*
  - *Luxury Goods and the Illicit Economy: A Case Study of Fraud in the World of Fine Wine*

EDUCATION

2020 Ph.D., International Studies, Old Dominion University
2004 M.S., National War College, National Defense University
1996 M.A., Naval Postgraduate School
1987 B.S., United States Naval Academy