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Marine plastic pollution: a review of the scientific evidence, current policies, and potential solutions

Hai Vuong

MARINE PLASTIC POLLUTION

A REVIEW OF THE SCIENTIFIC EVIDENCE, CURRENT POLICIES, AND POTENTIAL SOLUTIONS

HAI VUONG

A dissertation submitted to the World Maritime University (Malmö, Sweden) in partial fulfilment of the requirements of the (Typical) 14-month Standard (MSc) Programme for the award of the degree of Master of Science in Maritime Affairs taught in Malmö, Sweden.

2023

DECLARATION

I certify that, within my knowledges and understandings, any materials, which are referred to in this Dissertation and are the works of the others, have been identified, cited as in-text citations, or quoted, accordingly, to avoid plagiarism; and all materials, which are referred to in this Dissertation and are my own work(s), have been identified, cited as in-text citations, or quoted, accordingly; and that no material is included for which a degree has been previously conferred on me.

The contents of this Dissertation reflect my own personal views, in addition with the diversities of, *inter alia*, perspectives and views of the others, and are not necessarily endorsed by the World Maritime University (Malmö, Sweden).

Hai Vuong

September 26th, 2023

Supervised by: **Professor Johan Hollander**
(Degrees: Ph.D., B.Sc.)
World Maritime University (WMU), Professor in Sustainable Marine Management & Ocean Governance, Nippon Foundation Chair, Professor in Ocean Sustainability, Governance & Management (OSGM) Specialization;
Malmö, Sweden.

Supervisor's affiliation: **World Maritime University (City of Malmö, Sweden)**.

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[1] or the City of Malmö, or Malmö stad.
[2] Kristianstads kommun.

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Having accomplished the programme of Master of Science in Maritime Affairs (taught in Malmö, Sweden); and having finalized the Dissertation "Marine plastic pollution: A review of the scientific evidence, current policies, and potential solutions"[4], and having the Dissertation published by the WMU Library are among my privileges and honors, which come together with my special appreciation and gratitude sincerely delivered to all.

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[3] about which the reports were submitted to the MSEA Faculty after each field study.
[4] with 108 references (or items of references; see References on pages 59–73, and the last pages — pages 154–155), and submitted to the Turnitin of the WMU Academics (https://academics.wmu.se/).
[5] a member of the IAMU.

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[6] in marine navigation, sailing directions, ship maneuvering (or manoeuvering) and stability, bridge watch-keeping, nautical astronomy, navigational radar, paper charts and ECDIS (Electronic Chart Display and Information Systems), voyage planning, pilotage, standard marine communication, cargo handling, ballasting and de-ballasting, safety and security, and especially, the protection of the marine environment and the prevention of pollution from ships to the marine environment, *inter alia*.

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Cầu mong cho tất cả đều bình an, hạnh phúc, và thịnh vượng.

The Author

Hai Vuong

PREFACE

As a former marine navigating deck cadet-apprentice and deck officer on board of a sailing training ship and several sea-going cargo vessels[7], then working as a shore-based maritime administration personnel, and currently studying as a postgraduate student in maritime affairs and graduating from the above-mentioned MSc programme, I am fortunate having many opportunities to observe, engage, and learn about plastic and microplastic pollution and their relevant aspects, the potential solutions for the prevention, reduction, control, and gradual elimination of plastic and microplastic pollution. The previous and present positions allow me to have several viewpoints and perspectives, and to approach several perspectives, as well as to hear, to learn from, to respect, and to discuss about other perspectives from people about plastic and microplastic pollution, as well as their impacts on the environment, the nature, and humans.

Knowing that "shared knowledge lives and blossoms", and education, learning, studying, and researching are continuing, accumulating, and improving progresses, and recognizing the diversities of languages, their historical developments, revolutions, and adaptations, their complex systems of grammars and vocabulary, etc., with constructive and respectful approaches of contributing, building, and developing, I have conducted the Dissertation "Marine plastic pollution: A review of the scientific evidence, current policies, and potential solutions" with the ambitions to understand the current state of this global environmental challenge, its relevant aspects, and further to identify potential solutions to tackle the harmful impacts of plastic and microplastic pollution.

Considering the personal backgrounds as the previous cadet-apprentice and mariner-seafarer, and the present shore-based personnel and postgraduate student, the advantages (or strengths) and possible limitations, the burden of workload and respective timeframe, the knowledge and skills of English language as a foreign

[7] Before (2015 – 2019) and during the international outbreak of COVID-19 pandemic (2020).

language, and the knowledge of Maritime English, I am willing to discuss with new, constructive, and respectful recommendations and suggestions, to seek for common understandings. Also, knowing that any research works are not the final versions of their own, because researchers are continuously learning, studying, researching, improving, and innovating, and accordingly, their researches are continuously improved and updated, I am willing to discuss with constructive, contributing, and supporting feedbacks, to seek for common understandings, as parts of the progress of sustainable improvements and developments.

In general, there are some notes, which should be considered. In detail, the language that I use for, *inter alia*, academic writing, spelling, grammar, and synonyms in this Dissertation, is American English, with only some exceptional words and phrases are British English due to their original texts, and some phrases in Swedish language, Latin language, Russian language, and in my mother language. Besides, any lists, sequences, or series mentioned in this Dissertation, either in their numerical, alphabetical, or random orders, or any other orders, shall be considered as having equal weight and importance, or simultaneously necessary, or depending on their particular circumstances on a case-by-case basis.

To provide answer to any constructive and respective questions and feedbacks in cases of any misunderstandings, misinterpretations, arguments, confusions, uncertainties, or identifications of any mistakes with regards to any parts in this Dissertation, I am willing to discuss with publicly constructive and respectful questions and feedbacks, based on my knowledges, experiences, and understandings, and my perspectives and viewpoints, considering other perspectives, to seek for common understandings. The Dissertation's references, citations, paraphrases, or quotations of any parts within any referred materials are not necessarily equivalent to any partial or full supports, promotions, agreements, or endorsements for those particular parts and the rest of those referred materials in this Dissertation.

In this Dissertation, besides the referred materials from my work(s) and the others' works, there are references referred to the assignments, which I finished and submitted in fulfilment of the requirements of the Foundation Studies and

Specialization Studies in accordance with the requirements of the WMU's (Typical) 14-month Standard (MSc) Programme, Master of Science in Maritime Affairs taught in Malmö, Sweden. In addition, I captured all photographs[8] either during the sea-going services, the stay in Sweden, or the field study(ies).

This Dissertation shall be referred to within the scopes and the contexts of this Dissertation.

The Author

Hai Vuong

[8] or figures in general.

ABSTRACT

Title of Dissertation: **"Marine plastic pollution: A review of the scientific evidence, current policies, and potential solutions"**

Degree: **Master of Science in Maritime Affairs**
Taught in Malmö, Sweden; The WMU's (Typical) 14-month Standard (MSc) Programme.

Plastic waste is ubiquitous; and marine plastic pollution (MPP) in particular, plastic and microplastic pollution in general are becoming a global concern. Many researchers and institutions have different perspectives on this global environmental issue; for instance, in terms of major sources and pathways of plastics and microplastics, their physical and toxicological impacts on the marine environment, marine wildlife and marine ecosystems, on humans and human health, as well as on several anthropogenic activities. Besides, the links between climate change and plastic pollution are also among those perspectives. Nevertheless, many researchers and institutions agree on or provide supports to the fact that plastic and microplastic pollution originate from both land-based and sea-based sources, including ship-based sources, although many policies are currently in place. Some effective solutions are currently implemented in some countries and regions of the world; for instances, restriction of single-use plastics, sustainable and responsible production and consumption, "circular economy", environmentally sound management of waste, and awareness raising and cooperation among all stakeholders (all involved parties, including general public, scientific communities, industries, and policy-makers). These solutions have positive impacts on the prevention, reduction, and control of plastic and microplastic pollution. A gradual shift from a linear production-consumption pattern to a circular economy is promoted. Also, scientific research is needed to bridge the knowledge gaps for facilitating and implementing effective solutions in preventing, reducing, controlling, and gradually eliminating plastic and

microplastic pollution. The constructive discussions, concerted efforts, and collaborative cooperation among all stakeholders are of particular importance to tackle plastic and microplastic pollution. Recognizing the challenges and achievements, continuing with the current positive solutions, and developing and promoting innovative and sustainable solutions and approaches, the greener and more sustainable world in harmony with nature for the present generations and the future generations is being developed and strengthened by all of us.

Keywords: natural environments, nature, human beings, human health, climate change, entanglement (in plastic debris), (plastic and microplastic) ingestion, GHG emissions, wastes, garbage, debris, cigarette filters, single-use plastics, plastics, microplastics, pollutions, (synthetic) fibers, marine plastic pollution (MPP), chemicals, biological diversity, scientific knowledge gaps, sustainable development goals (SDGs), circular economy, marine environment, marine life, marine ecosystems, anthropogenic, shipping, maritime safety, human element, ALDFG, awareness raising and cooperation among all stakeholders, policies, solutions, prevention of pollutions, environmentally sound management of wastes, developing countries, vulnerable, habitats, etc.

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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

ALDFG	abandoned, lost, or otherwise discarded fishing gear
all stakeholders	all involved parties, including general public, scientific communities, industries, and policy-makers
Basel Convention	Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal
CBD	Convention on Biological Diversity
COLREG	International Regulations for Preventing Collisions at Sea, 1972 (or COLREGs)
EPS	expanded polystyrene (plastic polymer)
EU	European Union
European Parliament and Council	The European Parliament and the Council of the European Union
FSA	Formal Safety Assessment
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
GHG	greenhouse gases
GHS	United Nations Globally Harmonized System of Classification and Labelling of Chemicals
GRB	Garbage Record Book
GT	gross tonnage
HDPE	high-density polyethylene (plastic polymer)
HME	harmful substances to the marine environment
IAMU	International Association of Maritime Universities
III Code	IMO Instruments Implementation Code
ILO	International Labour Organization
IMDG Code	International Maritime Dangerous Goods Code
IMO	International Maritime Organization
IMSAS	IMO Member State Audit Scheme
IMSBC Code	International Maritime Solid Bulk Cargoes (IMSBC) Code

ISM Code	IMO's International Management Code for the Safe Operation of Ships and for Pollution Prevention (The International Safety Management Code)
ITOPF	International Tanker Owners Pollution Federation Limited
KUP	knowledge, understanding, and proficiency
LC/LP	The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 and the 1996 Protocol to the Convention (London Convention and London Protocol)
LDPE	low-density polyethylene (plastic polymer)
LL (Convention)	International Convention on Load Lines, 1966
LOA	length overall
London Convention	The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972
London Protocol	The 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972
MARPOL	The International Convention for the Prevention of Pollution from Ships
MCI	marine casualty investigation
MEPC	Marine Environment Protection Committee
MET	Maritime Education and Training
MLC (Convention)	Maritime Labour Convention, 2006
MPA	marine protected area
MPP	marine plastic pollution
MSC	Maritime Safety Committee
MSEA	Maritime Safety and Environmental Administration
MV	motor vessel
NGO	non-governmental organization(s)
OSPAR Convention	The Convention for the Protection of the Marine Environment of the North-East Atlantic
PE	polyethylene (plastic polymer)
PET	polyester (plastic polymer)
PMP	plastic and microplastic pollution
POPs	persistent organic pollutants

PP	polypropylene (plastic polymer)
PPE	personal protective equipment
PS	polystyrene (plastic polymer)
PVS	polyvinylchloride (plastic polymer)
RO Code	Code for Recognized Organizations
RO.	Research objective
RQ.	Research question
SDG	United Nations Sustainable Development Goals, a.k.a. Global Goals
SMS	Safety Management System
SOPEP	Shipboard Oil Pollution Emergency Plan
STCW Code	The Seafarers' Training, Certification and Watchkeeping (STCW) Code
STCW Convention	The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978 (STCW Convention)
Stockholm Convention	The Stockholm Convention on Persistent Organic Pollutants
STS	sailing training ship
The UNEA of the UNEP	The United Nations Environment Assembly of the United Nations Environment Programme
TM Convention	The International Convention on Tonnage Measurement of Ships
UEG	United European Gastroenterology
UK	United Kingdom
UN	United Nations
UNCLOS	The United Nations Convention on the Law of the Sea
UNEA	The United Nations Environment Assembly
UNEP	The United Nations Environment Programme
USA	United States of America
WMU	World Maritime University
▶	consequently, or recommendation(s)
etc.	

CHAPTER 1
INTRODUCTION

Plastic waste and microplastic fragments are ubiquitous in the natural environment; and marine plastic pollution (MPP) is becoming an alarming issue of global concern (Jambeck et al., 2015; Schwabl et al., 2019; The European Parliament & the Council of the European Union, 2019; Van Cauwenberghe & Janssen, 2014; Yang et al., 2015). Witnessing and recognizing the problematic issue of this global environmental challenge, the Author conducts the Dissertation research on the current state of MPP, its scientific evidence regarding the widespread occurrence and distribution, persistent characteristics, and harmful impacts on the marine environment, marine life, humans, human health and well-beings, and related activities, as well as the scientific knowledge gaps and challenges in tackling MPP.

Figure 1. *A pod of dolphins swimming and bow-surfing in front of a vessel's bow in the Atlantic Ocean* (Vuong, 2023c)

Besides, several international and regional instruments and documents are reviewed, which in combination with the recent discussions at international agendas, and the recommendations from many researchers, address potential solutions for the short-term and long-term goals of significant prevention, reduction, control, and gradual elimination of plastic pollution, for the purposes to effectively protect the marine environment, marine wildlife (Fig. 1), and thereby, protect humans, human health, and related anthropogenic activities.

One of the potential solutions is the gradual and sustainable transition from a linear production-consumption economy to a "circular economy" (Bonanno & Orlando-Bonaca, 2022; European Commission, 2018; Ford et al., 2022; UN, 2015; UN, 2021b). Recognizing the achievements from several models of practices to support the circular economy; for instance, 3R (UN, 2012), and 12R (Bonanno & Orlando-Bonaca, 2022), and considering the differences in capabilities and available resources at each level (ranging from individual, community, local, regional, to industrial, and beyond), the Author proposes a general and universal approach to sustainably continue contributing to the circular economy: $eR = eX$ (Formula 5, page 40). In detail, every individual person or larger settings can choose their contributing actions from $1R$ (or $1X$) to nR (or nX), depending on their appropriate and available means. Indeed, through the full, responsible, and constructive cooperation, participation and engagement from all stakeholders (including the general public, the scientific communities, the industries, and the policy-makers), these aforementioned short-term and long-term goals can be achieved.

Recognizing that the problem of MPP is extensive, complex, and transboundary in nature (Schmaltz et al., 2020; Wysocki & Billon, 2019), and different researchers and institutions have different perspectives on its relevant issues, the Author systematically conducts the research on MPP starting from the general background and the problem identification, then concentrating on the core questions as aforementioned and the cross-section discussions, and ultimately, concludes the research with recommendations for potential solutions and further research directions.

1.1 Background

As a matter of fact, although plastic waste and microplastic fragments have been entering the seas for many decades, only recently the issue of MPP has received public awareness at the international level (Mendenhall, 2021). Plastic debris and microplastic fragments are found everywhere, from coastlines, sea surface, and sea floor, to the air, marine protected areas (MPA), and even in the polar regions, (Bonanno & Orlando-Bonaca, 2022; Cózar et al., 2015; Jambeck et al., 2015; Jamieson et al., 2019; Schwabl et al., 2019; UNEP, 2014). While Schmaltz et al. (2020) and many researchers highlighted the fact that MPP is unequally distributed across countries and regions of the oceans (Jambeck et al., 2015); Mendenhall (2018) argued that marine plastic debris is beyond national jurisdiction of states and largely hidden from sight. In general, a majority of researchers provide support for or agree on the argument that densely populated coastal and urban areas, as well as industrial zones, especially in developing countries and middle-income countries, are major sources of mismanaged wastes and MPP, with rivers acting as a major pathway (Bonanno & Orlando-Bonaca, 2022; Cózar et al., 2015; Jambeck et al., 2015; Kwon et al., 2020; Meijer, 2021; Tanaka & Takada, 2016; UN, 2021b). This global concern of MPP, due to its transboundary nature, together with increasingly reported evidence of plastic bioaccumulation inside living organisms, is becoming "more serious and threatening" (Kurniawan et al., 2021).

Since its development into the commercial market in the 1930s and 1940s, plastic use has increased rapidly due to its essential role and advantages to human daily life (Jambeck et al., 2015; Almroth & Eggert, 2019; Schmaltz et al., 2020; The European Parliament and the Council of the European Union, 2019). In detail, Almroth and Eggert (2019), in agreement with many researchers, mentioned several benefits of these materials in our daily life, in particular to societal health, food safety, and energy efficiency (Schmaltz et al., 2020). For instance, plastics provide light materials for transport vehicles, thus will save fuel and reduce carbon dioxide emissions; also, high-performance insulation materials made from plastics greatly reduce energy consumption; likewise, plastics provide materials for food packaging and three-

dimensional printing technology implemented in various sectors. Critically important, plastic packaging, which is designed for short-lived applications and immediate disposal—in other words, single-use plastics—is the largest market sector due to its high functionality and relatively low cost (Jambeck et al., 2015; The European Parliament and the Council of the European Union, 2019). However, it is, unfortunately, estimated that plastics account for more than 80% of marine litter (Almroth & Eggert, 2019; European Commission, 2018). Especially, MPP is particularly serious in the oceans, where the accumulation of either macro-, micro-, or nano-plastics greatly damages the health of the marine environment (Bonanno & Orlando-Bonaca, 2022; Ferraro & Failler, 2020).

1.2 Problem statement

MPP, which accumulates from its land- and sea-based sources (Bonanno & Orlando-Bonaca, 2022; IMO, 2018d; Thiel et al., 2018), causes negative impacts on the marine environment, marine biodiversity, and potentially, humans and human health (Almroth & Eggert, 2019; Jambeck et al., 2015; Kurniawan et al., 2021; Mendenhall, 2021; UN, 2012; Wysocki & Billon, 2019). In detail, plastics can cause direct health effects to marine organisms due to ingestion of or entanglement in marine litter, and especially in abandoned, lost, or otherwise discarded fishing gear (ALDFG), which particularly affect species of conservation concern, e.g., marine turtles (Nelms et al., 2016; Thiel et al., 2018). Besides, invasive species and pathogens can be transported by hitchhiking with plastic debris; thus, these species can travel across habitats (Ford et al., 2022; UNEP, 2014). Furthermore, plastic debris deposits in bottom sediments — as its final destination in terms of sinking materials, causing deleterious effects on the benthic communities (Bonanno & Orlando-Bonaca, 2022); primarily due to its durability and persistent property in the marine environment, the progressive accumulation, the continuous process of natural fragmentation into smaller particles, and the concentration-dependent factor (Fok & Cheung, 2015; Gutow et al., 2016; Mendenhall, 2018; Thiel et al., 2018). In other words, because the natural degradation process of plastics is usually very long, the majority of plastic

materials and products ever manufactured still exist (Mendenhall, 2018). This phenomenon of plastic accumulation, together with the continuous fragmentation of plastic materials, increases the concentration of microplastic fragments in the marine environment; and thereby, increases the probability (or frequency) of interactions between the marine wildlife in general and the benthic community in particular with plastic debris and microplastic particles. In fact, plastic pollution disrupts the normal behavior of marine flora and fauna, and the normal functioning of marine ecosystems (Mendenhall, 2018); for instance, entanglement in plastic debris and ingestion of plastics and microplastics by marine animals, degradation of marine habitats, and the introduction of non-native and invasive species (Halleux, 2019; Rech et al., 2018). Many researchers agree that different sizes of plastic debris (macro-, micro-, and nano-plastics[9]) cause different harmful effects on the marine environment (Halleux, 2019; Kurniawan et al., 2021). In general, micro- and nano-plastic particles are considered to be more harmful compared to larger plastic debris (Kurniawan et al., 2021). Indeed, Critchell and Hoogenboom (2018) provided supports to the previous statement regarding these harmful effects from smaller particles; as the size of plastic fragments decreases, the ability of marine organisms to distinguish between normal food and contaminated food or non-food plastic particles decreases, and thereby, the frequency of plastic ingestion will increase. In addition, marine biodiversity and, especially, biodiverse habitats such as coral reefs are vulnerable to harmful impacts from marine plastic debris (Mendenhall, 2021); due to, for instance, smothering and abrading effects to such bio-diverse ecosystems.

Meanwhile, Ford et al. (2022) analyzed some fundamental links between climate change and MPP. For instance, plastics contribute to greenhouse gas (GHG) emissions throughout their lifecycle. Besides, according to the researchers, climate change, through extreme weather conditions and floods, exacerbates the spread of plastic

[9] Although there is an inconsistency in the definitions and size ranges used in scholarly and institutional literature, as different researchers and institutions have different perspectives (Browne et al., 2008; Mendenhall, 2018; Van Cauwenberghe & Janssen, 2014), the Author aligns the Dissertation research with commonly agreed definitions and size ranges (e.g., GESAMP, 2015; UN, 2021b); in detail, nano-plastics ($< 1\ micrometer$), microplastics ($< 5\ millimeter$), meso-plastics ($< 25\ millimeter$), and macro-plastics ($\geq 25\ mm$).

debris in the marine environment. As a result, marine ecosystems and marine wildlife are vulnerable to both climate change and this particular anthropogenic impact. To emphasize, MPP destabilizes marine ecosystems and destroys marine habitats, for example, by smothering and abrading coral reefs (Ford et al., 2022; Schmaltz et al., 2020), and leading to loss of marine ecosystem services, i.e., damages to economic activities such as shipping, fisheries, aquaculture, and tourism (Almroth & Eggert, 2019; European Commission, 2018; Mendenhall, 2018; Wysocki & Billon, 2019).

Critically important, the harmful impacts of MPP on human health are becoming an increasing concern (Jambeck et al., 2015), both in terms of physical and toxicological effects, due to the ingestion of microplastic particles and the consumption of the seafoods and sea products, which are contaminated with plastics, microplastics, and their associated chemical substances (Forrest & Hindell, 2018; Schwabl et al., 2019; Van Cauwenberghe & Janssen, 2014; Yang et al., 2015). In detail, according to Kurniawan et al. (2021), not only marine species but also humans can be affected by plastic pollution through the food chain. In detail, the bioaccumulation mechanism of plastics and microplastics in marine species is threatening all living organisms via the food chain (Kurniawan et al., 2021; Van Cauwenberghe & Janssen, 2014). Since fishes, seafoods, and sea products are major sources of protein and essential elements for humans, there is a potential that humans—as the top consumer in the food chain—we will be affected by these plastic and microplastic particles (Yang et al., 2015). Critically important, various hazardous chemical substances, either additives (used in plastic manufacture) or contaminants (accumulated in the bottom sediments and absorbed by plastic and microplastic fragments) are toxic and may cause harmful impacts on human health (Mendenhall, 2021; Tanaka & Takada, 2016; Van Cauwenberghe & Janssen, 2014; Wysocki & Billon, 2019; Yang et al., 2015).

Despite of the urgency of the global concern, some aspects regarding MPP remain unknown (Almroth & Eggert, 2019). For instance, there is an uncertainty in determination of sources, pathways, and negative impacts of MPP (Mendenhall, 2021). Especially, Jambeck et al. (2015) mentioned the unknown quantity of plastics

entering the oceans from land-based sources. Similarly, there are knowledge gaps regarding plastic bioaccumulation and biomagnification in human bodies, as the topic is relatively new (Kurniawan et al., 2021).

Understanding the general background of MPP and its relevant problematic issues, the Author studies perspectives and researches from scholarly and institutional sources, to further explore the current state of MPP, its scientific evidence, and identify the scientific knowledge gaps and challenges, as well as to examine the current policies in tackling MPP. All in all, the Author aims at identifying potential solutions for sustainable prevention, reduction, control, and gradual elimination of plastic and microplastic pollution (PMP).

1.3 Research objectives and research questions

In total, there are four research questions supporting two research objectives (Table 1). The first research objective requires an identification of the current state and scientific evidence (Research question 1.1), and knowledge gaps and challenges regarding MPP (Research question 1.2). Afterwards, by reviewing the current policies from the International Maritime Organization (IMO) and other institutions in tackling MPP (Research question 2.1), and analyzing perspectives from different scholarly and institutional sources, as well as identifying recommendations for potential solutions (Research question 2.2), the second research objective can be achieved.

Table 1

Research objectives and research questions

Research objectives	Research questions
RO.1 To identify the current state, scientific evidence, knowledge gaps, and challenges regarding MPP.	**RQ.1.1** What is the current state and scientific evidence regarding MPP? **RQ.1.2**

	What are the knowledge gaps and challenges regarding MPP?
RO.2 To review and analyze the current policies and perspectives regarding MPP of the IMO and other institutions, as well as from different scholarly and institutional sources, and thereby, identify recommendations for potential solutions in tackling MPP.	**RQ.2.1** What are the current policies from the IMO and other institutions in tackling MPP? **RQ.2.2** What are recommendations for potential solutions in tackling MPP?

1.4 Dissertation structure

First, the dissertation research introduces the background and problem statement concerning plastic pollution, followed by a list of research objectives and their respective research questions. Then, there is an outline of the dissertation structure. Following the introduction, the *second* part discusses the methodology and research design. The *third* part — Literature review is of fundamental importance. This part builds the foundation of the dissertation research, as topics regarding MPP, including, the current state, scientific evidence, knowledge gaps, and the current policies are discussed in detail.

Fourth, based on the foundation knowledge, and conducting analyses and critical thinking, the potential solutions in tackling MPP are discussed. The *fifth* part — Discussion bridges the gaps between sections, as well as clarifies the intersections and points of interest. Finally, the *sixth* part — Summary and Conclusions sum up the research work.

CHAPTER 2
METHODOLOGY

2.1 Methodology

Generally, there are three methods; namely, systematic literature review, secondary data analysis (or archival study), and comparative study, which are utilized in the second stage of the research — data analysis. With regard to the justification of the chosen methods, it is certain that those three applied methods are sufficient in obtaining answers to the research questions. To emphasize, as the input data consists mainly of written documents and articles, a systematic approach is crucial to identify similarities and differences, contradictions, and limitations among literature materials. Besides, one of the purposes of the research is to identify the scientific knowledge gaps, the advantages and disadvantages of the current implemented measures and policies, and the suggestions for potential solutions in tackling MPP. Therefore, archival study and comparative study are adequate in this case, following systematic categorization of materials.

2.2 Research design

The Author conducts the Dissertation research processing mainly with two types of literature; namely, legal documents and scholarly articles (Fig. 2). While the former is retrieved from respective institutions, e.g., the UN, UNEP, IMO, and EU; the latter is collected from scholarly databases, e.g., mainly Scopus and ScienceDirect (besides, Google Scholar, EBSCO OneSearch, and the WMU Library), utilizing Boolean search operators (1) and (2), and other additional search strings (3). In fact, legal documents and instruments are specific and limited in their amount, whereas scholarly articles and reviews require a time-consuming process for sorting, assessing, and analyzing. Upon obtaining an initial collection of reading materials (Stage 1), key finding, which are obtained therefrom, are categorized by themes, and tagged accordingly (4).

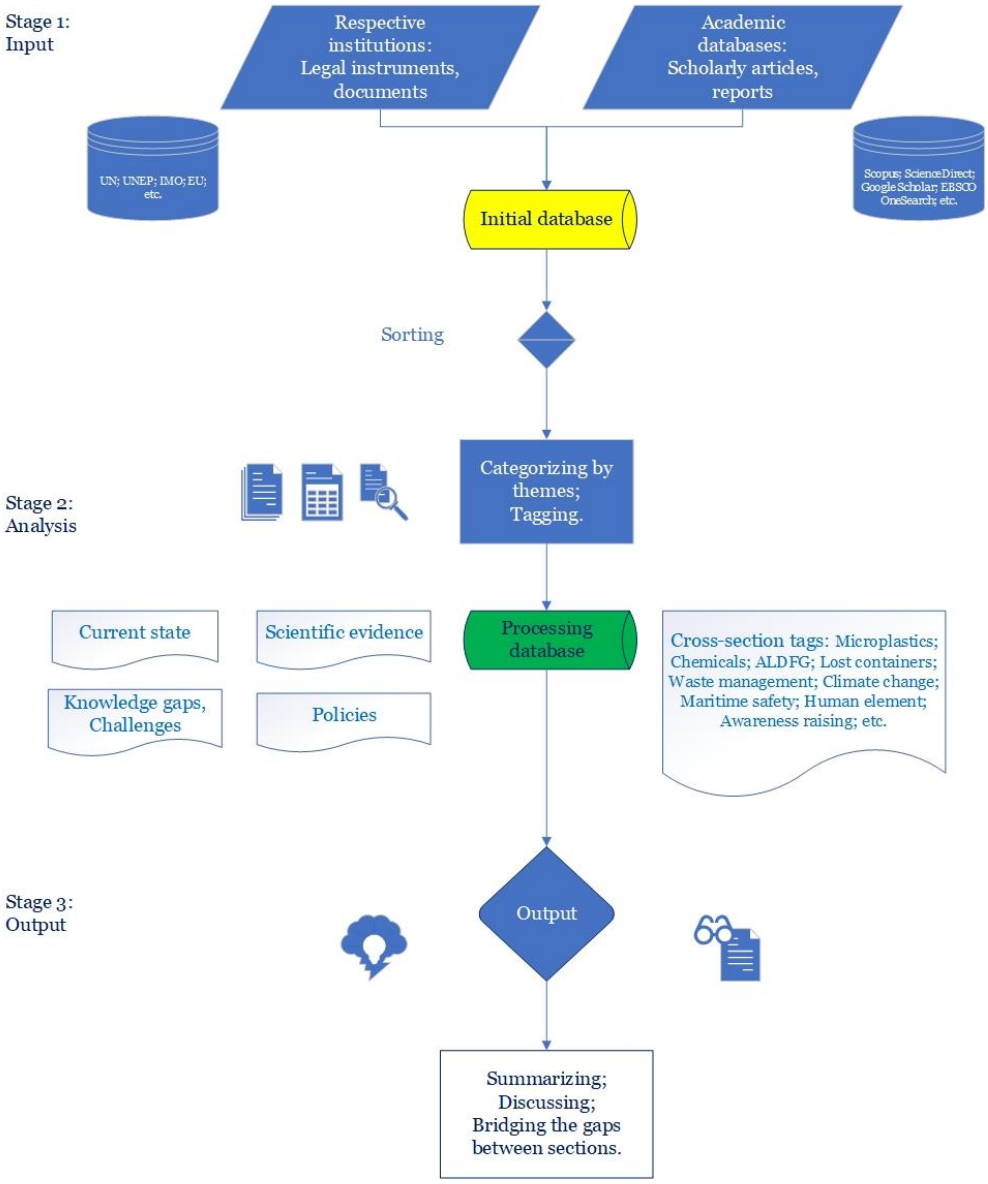

Figure 2. *Research process*

Search string utilizing Boolean operators: (1)
"marine plastic pollution"

Search string utilizing Boolean operators: (2)
marine AND plastic AND pollution

Additional search strings: (3)
Microplastics; Chemicals; ALDFG; Lost containers; Waste management; Climate change; Maritime safety; Human element; Awareness raising; etc.

Tags:
[1_Current_state]; [2_Scientific_evidence]; [3_Knowledge_gaps];
[4_Knowledge_gaps_Solutions]; [5_Challenges]; [6_Microplastics];
[7_Current_policies]; [8_Potential_solutions]. (4)

Consequently, the legal instruments, documents, scholarly articles, reviews, and reports are sorted and processed by each stack (Stage 2). These processing data are then analyzed by a combination of the three above-mentioned methods (i.e., systematic literature review, secondary data analysis, and comparative study). Afterwards, through the analysis, the output data can be obtained (Stage 3).

CHAPTER 3
LITERATURE REVIEW

3.1 Marine plastic pollution: The current state

Although plastics are essential materials, which are applied in many sectors of human daily life and contribute to solutions of many societal challenges (Almroth & Eggert, 2019; Bonanno & Orlando-Bonaca, 2022), plastic pollution has emerged as more serious global threats to the natural environment and the human environment in general and the marine environment in particular (Ferraro & Failler, 2020; Kurniawan et al., 2021). This literature review discusses several aspects of this global problem, ranging from the current state, scientific evidence, knowledge gaps and challenges, to the current policies, which are presented in Sections 3.1, 3.2, 3.3, and 3.4, respectively. In the first place, this section provides a general picture of the current state of MPP.

In general, there are several types of plastic polymers[10], which are commonly used and dominantly found in the marine environment as plastic wastes. To satisfy particular applications with required properties, these polymers are blended or supplemented, in the process of plastic manufacturing, with chemical additives, e.g., plasticizers, heat or light stabilizers, flame retardants, antioxidants, and foaming agents (Bonanno & Orlando-Bonaca, 2022; UNEP, 2002). These diverse polymer structures and physical characteristics, together with their constituent components cause these plastic wastes having different behaviors and effects in the marine environment; for instance, high-density plastic polymers sink in the water column and eventually, accumulate in the bottom sediment; whereas, single-use plastics, which often consist of less dense polymers, float on the water surface and end up at shorelines (Almroth & Eggert, 2019; Kurniawan et al., 2021). In addition, Kurniawan et al. (2021) highlighted that these differences in physical characteristics and chemical additives also create distinctions in their degradation mechanisms and recycling methods. In

[10] These include, *inter alia*, polyethylene (high-density HDPE, and low-density LDPE), polypropylene (PP), polyester (PET), polystyrene (PS), expanded polystyrene (EPS), polyvinylchloride (PVS), which are different in their physical characteristics and areas of application (Almroth & Eggert, 2019; GESAMP, 2015; Kurniawan et al., 2021; UNEP, 2002).

fact, the statistics show that, among the huge amount of cumulative production of plastics, approximately 80% has been accumulated in the natural environment or landfill sites, and about 20% has been incinerated or recycled (Almroth & Eggert, 2019).

This anthropogenic pressure of MPP causes negative impacts not only to the marine wildlife and ecosystems, but also to the human health; for instance, via the food chain (Kurniawan et al., 2021), and other anthropogenic activities, e.g., fisheries and aquaculture, shipping, and tourism (Bonanno & Orlando-Bonaca, 2022). Globally, there are continuously increasing reports of scientific evidence regarding the presence of plastic particles inside bodies of various species (Kurniawan et al., 2021), and even inside human guts (Schwabl et al., 2019). Recognizing the complexity and transboundary nature of MPP, many researchers address the current challenges and knowledge gaps in many aspects regarding this global concern, which require further researches to strengthen and support the science-policy interface (Bonanno & Orlando-Bonaca, 2022). Currently, there are a limited number of international binding instruments in dealing with plastic pollution (Kurniawan et al., 2021). For instance, UNCLOS is the only international binding convention regulating land-based sources of pollution in general (UN, 1982); whereas, MARPOL and LC/LP regulates activities in connection with marine pollution and plastic pollution from ship-based and sea-based sources (IMO, 1972; IMO, 1973). Besides, several regional instruments and agreements also address the issues and establish measures to eliminate the severe impacts from plastic pollution; for instance, the restriction of certain plastic products in the EU (The European Parliament & the Council of the European Union, 2019), and the established measures from the OSPAR regions in dealing with this anthropogenic pressure (OSPAR, 1992). Furthermore, at international levels, many intensive and continuous discussions are conducted for more effective solutions and regulations to tackle the problematic issues of MPP (Bonanno & Orlando-Bonaca, 2022); for instance, the United Nations Environment Assembly of the United Nations Environment Programme (the UNEA of the UNEP), as well as many researchers underscored the urgent necessity of developing an international binding instrument on

the prevention, reduction, and control of plastic pollution (Ferraro & Failler, 2020; UNEP, 2022); whereas, the on-going works at the IMO navigate towards the enhancing and strengthening of management of fishing vessels (including their safety and personnel, and especially, marking of fishing gear to tackle the issues of ALDFG), together with the management of lost containers at sea (Hwang, 2020; IMO, 2018d).

To summarize, it is undoubtedly convinced that plastics are polluting the environment and the oceans (Bonanno & Orlando-Bonaca, 2022; Kurniawan et al., 2021). Despite of the urgency and severity of the global anthropogenic problem of MPP, there are a wide range of challenges and gaps in both knowledge and governance, which require further scientific researches and cooperation at all levels, and in particular at international levels. Together with scientific researches, awareness raising and engagement of all stakeholders are of particular importance (Bonanno & Orlando-Bonaca, 2022); thus, these will greatly support the development of potential solutions at global level to tackle the problematic issues and adverse impacts of MPP in particular, and to prevent, reduce, control, and gradually eliminate plastic and microplastic pollution in general.

3.2 Marine plastic pollution: Scientific evidence

Anthropogenic plastic debris in general and microplastics in particular are ubiquitous in the marine environment (Bonanno & Orlando-Bonaca, 2022). This part of the Dissertation focuses on the scientific evidence regarding the omnipresent nature of this anthropogenic pressure and its impacts on the marine environment through conducting a study of scholarly literature, including research articles, laboratory experiment reports, as well as reviews and surveys. The evidences are divided into three main categories; namely marine life, polluted sites, and human-consumption-related researches. These paragraphs below discuss those scientific evidence with regard to each category[11], respectively.

[11] In addition, Table S1 summarizes the reviewed materials regarding the scientific evidence (Appendix A).

Obviously, as more and more plastic wastes find their ways into the oceans, together with the continuous process of fragmentation of plastics into smaller particles (Critchell & Hoogenboom, 2018), the accumulation of microplastics in the marine environment increases; consequently, the probability of interaction between MPP and **marine flora and fauna** will also increase. Thiel et al. (2018) underscored the unequal harmful impacts on marine life from interaction with plastics. According to their extensive review on 97 documented vertebrate species (including marine turtles, marine mammals, fishes, and seabirds) in the studied areas of Southeast Pacific, there are two main dependent factors of the MPP interactions: the feeding behaviors of the species, and the distribution and accumulation of plastics. With regard to sources of origin, the anthropogenic marine debris, in general, originates from both land-based and sea-based activities (Nelms et al., 2016; Thiel et al., 2018), including, *inter alia*, coastal population, beaches, aquaculture, and fisheries (mainly in connection with ALDFG). Similarly, in terms of Spanish coastline, Rech et al. (2018) underscored that important sources of marine litter, among which plastics are dominant with regard to the total amount surveyed, are from fishing and aquaculture activities. Particularly important, shipping- and port-related activities also account for the problematic issues of MPP (Browne et al., 2010; Cózar et al., 2015; Kwon et al., 2020). The primary negative impacts from this anthropogenic pressure on the marine life include, *inter alia*, plastic ingestion and entanglement (Thiel et al., 2018), and transport of invasive species (Rech et al., 2018).

Among those aforementioned vertebrates, marine turtles, species of which inhabit in the major ocean and sea basins of the Atlantic, Indian, Pacific, and Mediterranean, as well as in the Japan's water, suffer the most from both entanglement and ingestion (Duncan et al., 2019; Fukuoka et al., 2016; Nelms et al., 2016; Thiel et al., 2018); whereas, planktivorous fish is the most vulnerable species to plastic ingestion due to their feeding biology, either in the natural conditions (Thiel et al., 2018), or in aquarium-based conditions (Critchell & Hoogenboom, 2018). Concerning impacts on marine turtle species, there are two pathways of plastic ingestion: either indirect or direct (Nelms et al., 2016). Accidental ingestion occurs when there is a

mixture of normal prey and plastics (Nelms et al., 2016), or contaminated prey acting as vector of trophic transfer (Duncan et al., 2019); whereas, direct consumption of plastics is caused by mistaken identity as prey (Nelms et al., 2016), due to the similarity in transparent characteristics and drifting behaviors of plastic debris (Fukuoka et al., 2016), especially in areas of contaminated water column or sediments being sources of plastic pollution (Duncan et al., 2019). Besides impacts at individual level, MPP also significantly affects the population level of marine turtles; for instance, by altering the sex ratios during hatchling seasons; consequently, disrupting the total productivity of the wider ecosystems (Nelms et al., 2016). Regarding fish species, the similar misidentification mechanism (as in the case of the above-mentioned marine turtles) also causes those animals suffering from plastic ingestion; for example, northern anchovy (Savoca et al., 2017) and planktivorous fish (Thiel et al., 2018; Critchell & Hoogenboom, 2018).

Navigating towards the Southern Hemisphere, by researching at the Tasman Sea, Wilcox et al. (2015) underscored the significantly high percentage of approximately 60% of studied seabird species examined with ingested plastic particles in their guts. The researchers, based on the fact of more plastic abundance at sea, expected that the rates of plastic ingestion also increase; and consequently, predicted that by 2050, this anthropogenic pressure will affect approximately 100% of all seabird species.

Equally important, cases of entanglement (mostly into ALDFG) of marine mammals, including, e.g., whales, dolphins, porpoises, seals, sea otters, and sea lions, are also documented (Thiel et al., 2018); of which the frequent scenario consequences upon entanglement are similar: suffering from suffocation and drowning.

Besides those reviewed vertebrates, other marine invertebrates, flora and fauna, e.g., seaweed, bivalves, jellyfish, and amphipods, are also affected by MPP (Browne et al., 2008; Gutow et al., 2016; Jamieson et al., 2019; Macali et al., 2018). In detail, seaweeds as a vector transfer microplastics from water in laboratory conditions to marine herbivorous consumers (periwinkles), and consequently, into marine food chains (Gutow et al., 2016). The researchers also highlighted the inability of these marine meso-herbivores in distinguishing between clean algae with contaminated

algae. Another laboratory experiment was also conducted to investigate impacts on sampled mussels (Browne et al., 2008). The research underscored the translocation of microplastics from those animals' gut to their circulatory system, as well as the long persistence period (over 48 days) of the ingested particles. Browne et al. (2008), therefore, concluded with an assumption of the causal effect between this persistence period and the possibility of tissues' contamination by chemical additives associated with microplastics. The confusion or wrong recognition of plastics as prey also occurs in terms of jellyfish (Macali et al., 2018), possibly due to the concentration of drifting litters and planktonic species in the same geographic area (as in the case of the Mediterranean Sea).

In addition, it is of particular importance to mention the role of those "key prey" in the marine trophic levels, e.g., jellyfish, mussels, and northern anchovies (Browne et al., 2008; Macali et al., 2018; Savoca et al., 2017). According to these studies, as lower-level preys in the marine food webs, upon being contaminated with microplastics, these animals act as transferring vectors; thus, the top predators, including humans, consume these prey species, and as a consequence, these chains will further affect marine wildlife and marine ecosystems.

Critically important, Jamieson et al. (2019) publish the first record of plastic contamination and microplastic ingestion in several studied sites of the greatest depths of the oceans, i.e., six deep-ocean trenches of the Pacific Ocean, including, Izu-Bonin, Japan, Kermadec, Mariana, New Hebrides, and Peru-Chile. These surveyed sites are located at huge distances between each other, both horizontally (distances ranging from over 8,000 km to over 15,000 km) and vertically (depths ranging from 7,000 m to approximately 11,000 m), which reaffirm the omnipresence of the anthropogenic debris in general, and microplastics in particular.

In another category — **polluted sites**, the reviewed papers focus on three main locations; namely, river estuaries (Browne et al., 2010; Kurniawan & Imron, 2019), coastal areas and beaches (Fok & Cheung, 2015; Kwon et al., 2020), and sea surfaces (Cózar et al., 2015). *In the first place*, two estuary areas from the representative countries in Europe and Asia, one — the Tamar River (UK), and the other — the

Wonorejo River (Indonesia), were surveyed for anthropogenic debris. In the estuarine shorelines of the Tamar River, microplastics accounted for the majority of recorded debris, with over 60% of the total amount (Browne et al., 2010). Besides packaging plastics, shipping- and fishing-related materials, e.g., ropes used on vessels, fishing lines, were also detected in the areas (Browne et al., 2010). The research showed that wind, water flow movement, and density of particles are among those affecting factors on the spatial distribution and accumulation of plastics; whereas, Kurniawan and Imron (2019) underscored that the plastic accumulation correlates with the tidal effect, with a significantly higher plastic abundance during high tide. Regarding plastic types, PE and PP are the most abundant in both estuarine areas. In terms of management aspects, Browne et al. (2010) highlighted another source of microplastic input to the estuary is the operations and discharges of local sewage treatment plants; whereas, Kurniawan and Imron (2019) considered the importance of plastic prevention measures from the sources, which can greatly contribute in avoidance of plastic fragmentation in the environment.

Second, the other studies were conducted in the coastal areas of Korea (Kwon et al., 2020) and the beaches of Hong Kong (Fok & Cheung, 2015). Their results converged at the findings of densely populated urban areas, with large-scale anthropogenic activities, e.g., sea ports, industrial complexes, becoming the greater contributors of microplastic pollution, which enters the marine environment primarily through, *inter alia*, major rivers. Regarding plastic types, EPS, convergently, in both areas, was dominant among surveyed samples. Particularly, microplastics account for over 90% of the total collected amount in the Korea's coastal areas; whereas, Hong Kong's beaches are considered as a hotspot of microplastic contamination.

Third, according to Cózar et al. (2015), the busy area of Mediterranean Sea with major international shipping routes is identified as "a region of particular high plastic concentration". Likewise, all sample attempts (100%) were recorded with plastic debris, of which microplastics accounted for over 80% in terms of amount collected. All in all, these researchers addressed their recommendations regarding waste collection and management in tackling MPP; for instance, Fok and Cheung (2015),

and Cózar et al. (2015) agreed with Kurniawan and Imron (2019) on focusing on plastic reduction and prevention at their sources from entering the oceans within waste management strategies.

The last category of scientific evidence is related to **human consumption**, noting that there are some convergences as discussed above in the category "marine life" with regard to the marine food webs and the mechanism of transferring vectors. In detail, studies were conducted investigating the relations between plastic-contaminated food (including table salt, edible seaweed, fishes, and bivalves), and human consumption, as well as the potential impacts on human health. *First of all*, commercial table salt was sampled from different brands worldwide, including China (Yang et al., 2015), Spain (Iñiguez et al., 2017), Australia, France, Japan, Malaysia, Portugal, and South Africa (Karami et al., 2017). The results showed that microplastic particles were detected in these samples, which reaffirms that microplastics are ubiquitous in sea water all over the world; and sea products are, therefore, contaminated by microplastics (Yang et al., 2015). Convergently, among plastic types found in those samples, PET, PP, and PE are the most dominant (Iñiguez et al., 2017; Karami et al., 2017; Yang et al., 2015). While Karami et al. (2017) underscored the concern of the potential effects on human health from consuming sea products contaminated with microplastics in the long term; Yang et al. (2015) and Iñiguez et al. (2017) highlighted the threats to food safety posed by chemical additives and contaminants, especially, persistent organic pollutants (POPs), which may be absorbed by microplastic particles, and through the mechanism of transferring vector, entering the marine trophic levels to sea products, and finally, going upward to the apex consumers, including humans.

Second, edible seaweed was studied in laboratory conditions for identification of plastic contamination (Sundbæk et al., 2018). The outcome of the research demonstrated evidence of PS microplastic particles adhering to the algae, of which a small proportion was still remained on its surface after washing process. The researchers, therefore, raised the need for further study on seaweed acting as vector transferring microplastic pollution to humans.

Third, regarding fishes for human consumption, microplastics were found in gastrointestinal tracts of approximately 80% of the total sampled Japanese anchovies in the case of Japan (Tanaka & Takada, 2016), and of approximately 25% of total sampled species in the case of the remote islands in South Pacific (Forrest & Hindell, 2018). The research conducted in Japan showed that PE and PP were the most dominant plastic types detected in these anchovies, which are a common food in the country. Likewise, as discussed earlier, these studies raised concern regarding human exposure to hazardous chemicals or harmful substance associated with microplastics through the upward transferring mechanism within the marine food chains. *Fourth*, the study on mussels and oysters originated from the North Sea also documented the exposure to any pollutants in the seawater, including microplastics (Van Cauwenberghe & Janssen, 2014). As a matter of fact, the evidence of microplastic contamination in fish species in South Pacific islands, combining with the remoteness of those studied sites, underscores the omnipresent and widespread nature of this particular anthropogenic impact (Forrest & Hindell, 2018). Convergently, Tanaka and Takada (2016) confirmed that marine ecosystems have been infiltrated by microplastics globally.

Another factual evidence was reported through the study of the presence of plastic particles in human stools (Schwabl et al., 2019; UEG, 2018). In detail, analysis of stool samples, which were collected from individuals from Austria, Finland, Japan, Italy, Netherlands, Poland, Russia, and United Kingdom, showed that plastic particles and fibers were detected in all samples (100%). Consequently, based on this result, it is estimated that microplastics might be detected in the stool of over half of the world's population. The dominant types of plastics were PP and PET, which converge with those aforementioned findings regarding dominant microplastic types found in table salt and fishes for human consumption. Similarly, Schwabl et al. (2019) raised concern regarding the harmful impacts from microplastics on human health. Moreover, the researchers addressed the need for further study in the potential scenarios, where the smallest microplastic particles may enter the liver, blood stream, or lymphatic system (Schwabl et al., 2019; UEG, 2018).

Ultimately, the impacts of marine anthropogenic debris, microplastic pollution, and their associated chemicals are discussed within the scope covering three categories, including marine life, polluted sites, and human-consumption-related. From the hotspots of plastic pollution in Hong Kong and the Mediterranean Sea, reaching to the remote South Pacific islands, and sinking further to the greatest depths of the oceans, among other locations in the marine environment and its coastal areas, plastic debris in general and microplastics in particular are ubiquitous, which significantly to severely affect not only the marine trophic levels from the base to the apex, but also humans, human health, and various anthropogenic activities. In recommending the effective solutions, many researchers agree on the improvement of the waste collection and management system, as well as the concentration on waste reduction and prevention within waste management strategies (Cózar et al., 2015; Fok & Cheung, 2015; Kurniawan & Imron, 2019; Thiel et al., 2018). Equally important, enhancing environmental education, raising public awareness and involvement with regard to the problematic issues of MPP are also underscored (Thiel et al., 2018; Nelms et al., 2016). Especially, altering and changing consumer behaviors in terms of single-use plastics, e.g., packaging and utensils, should also be considered, as in the case of the Asia's representative hotspot of microplastic contamination — Hong Kong, where the use of plastic bags and packaging becoming a common practice (Fok & Cheung, 2015). To conclude this part in the best approach, citing these following findings from the reviewed literature further supports those aforementioned scientific evidence: the lead researcher Dr. Philipp Schwabl addressed his comment on their study reaffirming that "plastics ultimately reach the human gut" (UEG, 2018); whereas, in terms of the ubiquity of MPP, Jamieson et al. (2019), in their research, eventually, rigidly assumed the probability of "no marine ecosystems left that are not impacted" by these anthropogenic pressures.

3.3 Marine plastic pollution: Knowledge gaps and challenges

Although many researchers have conducted their studies on MPP and its adverse impacts on the environment and human health, the knowledge and understanding regarding its sources, interacting and affecting mechanisms, as well as other relevant aspects are still limited (Bonanno & Orlando-Bonaca, 2022), which are in contrast with the increasing global concerns regarding this problematic situation. Pursuant to Principle 15 of the Rio Declaration on Environment and Development (UN, 1992b) in particular, and other principles thereof in general, precautionary measures shall be implemented by States to the fullest extent, and especially, cost-effective measures for the prevention of the environmental degradation shall not be postponed due to the insufficiency of scientific understanding, which can be enhanced by cooperation, capacity building, and exchanges of scientific and technological knowledge among States (in accordance with Principle 9).

In detail, through analyzing the research materials, the Author groups scientific knowledge gaps[12] into three categories; namely, fundamental and general knowledge, human-health-related, and marine-life-related. Within the first category, many researchers emphasized the lack of information on sources and pathways of MPP, stage-specific contributing quantity, causes of harmful effects, and the co-occurrence of climate change and plastic pollution (Almroth & Eggert, 2019; Ford et al., 2022; Jambeck et al., 2015; Mendenhall, 2018). Regarding human-health-related category, the studies are rather scarce on the exposure of microplastics to humans via contaminated seafoods, including, sea vegetables, as well as their associated mechanisms of transferring vectors (Almroth & Eggert, 2019; Forrest & Hindell, 2018; Gutow et al., 2016; Mendenhall, 2018; Schmaltz et al., 2020; Sundbæk et al., 2018; Van Cauwenberghe & Janssen, 2014). In terms of marine-life-related gaps, further research and attention are required to understand the impacts on marine organisms, including marine turtles and marine mammals, especially in hotspots of MPP accumulation, hadal zones of the ocean, and remote locations worldwide (Cózar et al.,

[12] Table S2 summarizes the knowledge gaps in detail, which are retrieved from the reviewed materials and grouped by categories, together with recommendations (if any) from respective researchers.

2015; Duncan et al., 2019; Jamieson et al., 2019; Mendenhall, 2018; Thiel et al., 2018). Besides, more understanding is needed for the translocation mechanism of microplastic particles from the gut cavity to the circular system of marine organisms, and consequential impacts on individual and population levels (Browne et al., 2008; Wilcox et al., 2015).

As a matter of fact, this significant lack of scientific knowledge regarding MPP and all of its relevant aspects create challenges in understanding this global issue and further, in formulating and implementing targeted interventions and effective policies (Mendenhall, 2018).

In terms of challenges[13], those difficulties normally arise from or connect with the characteristics of plastic materials, the research features, or management and governance activities. In fact, because the size of microplastic particles is small, and MPP is mostly out of sight and harmful in transboundary movements, clean-up activities and remediation solutions encounter various challenges (Almroth & Eggert, 2019; Jambeck et al., 2015; Mendenhall, 2018). Besides, the existence of the inconsistency within the body of knowledge also creates barriers to further researches, as different researchers and institutions use different definitions, terminologies, and size ranges for plastic particles (Browne et al., 2008; Duncan et al., 2019; Ferraro & Failler, 2020; Fok & Cheung, 2015; Forrest & Hindell, 2018; Mendenhall, 2018; Nelms et al., 2016; Van Cauwenberghe & Janssen, 2014; Wysocki & Billon, 2019). In terms of difficulties in management and governance, many researchers highlights the challenges in the existing regulatory framework, mainly due to the significant knowledge gaps and their relevant uncertainty, as well as technical challenges in waste management and plastic recycling, which require concerted efforts and collaborative contributions from all stakeholders (Almroth & Eggert, 2019; Forrest & Hindell, 2018; Hwang, 2020; Kurniawan et al., 2021; Mendenhall, 2018; Schmaltz et al., 2020; UNEP, 2019c; Wysocki & Billon, 2019).

[13] Similarly, Table S3 summarizes the challenges, which are concluded by many researchers and grouped by categories.

3.4 Marine plastic pollution: The current policies

At the global level, there are several international instruments in regulating pollution and relevant aspects (Ferraro & Failler, 2020). This part reviews six international conventions, including, UNCLOS[14], MARPOL[15], LC/LP[16], Stockholm Convention[17], Basel Convention[18], and CBD[19]. These international instruments are categorized in three groups; namely, pollution-controlled, chemical-controlled, and biodiversity-oriented. Table 2 summarizes these instruments, their areas of application, advantages and disadvantages; whereas, a more detailed review can be referred to in the Supplement materials (Appendix D). Afterwards, the following paragraphs briefly introduce the regional instruments and agreements, as well as the IMO's relevant instruments and strategies.

Table 2

The reviewed instruments (by categories)

Instrument	Advantages / Disadvantages / Challenges
POLLUTION-CONTROLLED	
UNCLOS	UNCLOS addresses both land-based and sea-based sources of pollution; UNCLOS does not specifically address marine plastic litters and microplastics.
MARPOL	MARPOL addresses ship-based sources of pollution;

[14] The United Nations Convention on the Law of the Sea (UNCLOS)
[15] The International Convention for the Prevention of Pollution from Ships (MARPOL)
[16] The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 and the 1996 Protocol thereto (London Convention and London Protocol, LC/LP)
[17] The Stockholm Convention on Persistent Organic Pollutants (Stockholm Convention)
[18] The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (Basel Convention)
[19] The Convention on Biological Diversity (CBD)

	In terms of Annex V, there are lower limits for the requirements, i.e., the minimum gross tonnage (GT) and the minimum number of persons carried on board.
LC/LP	LC/LP regulate the intentional dumping and incineration activities at sea.
CHEMICAL-CONTROLLED	
Basel Convention	Plastic wastes are categorized as "other wastes".
Stockholm Convention	Certain chemical substances, which are associated with plastic production, are regulated under the Convention.
BIODIVERSITY-ORIENTED	
CBD	The issues of marine litter, plastics, and microplastics are not directly addressed.

Within the **pollution-controlled** category, the Author reviews three international conventions. *In the first place*, the **United Nations Convention on the Law of the Sea** (UNCLOS) is a legal framework for the seas and the oceans, all issues relating to the law of the sea, and all activities carried out therein, for the purposes of "maintenance of peace, justice and progress for all peoples of the world" in general, and for the protection and preservation of the marine environment in particular (UN, 1982; UN, 2012; UN, 2021a). In terms of the marine environment and related aspects, UNCLOS establishes legally binding obligations upon the States Parties for not only ship-based and sea-based sources of pollution, but also for the prevention, reduction, and control of pollution of the marine environment from land-based sources. In detail, Part XII of UNCLOS establishes regulations regarding the protection and preservation of the marine environment, of which the first six sections are thoroughly reviewed, including general provisions (Section 1), cooperation and technical assistance (Section 2 and Section 3), monitoring and assessment (Section 4), international rules and

national legislation (Section 5), and ultimately, enforcement (Section 6). Among these sections, Section 5 and Section 6 establish provisions concerning the international rules and national legislation in the prevention, reduction, and control of marine pollution, as well as measures for enforcement by flag States, port States, and coastal States. It is important to mention that in Section 5 and Section 6, provisions are oriented by sources of pollution, i.e., land-based, sea-based (including sea-bed activities and activities in the Area), by dumpling, and ship-based, as well as air pollution from or through the atmosphere. Table 3 demonstrates the relevance of provisions in Section 5 and Section 6 in terms of source-based division.

Table 3

UNCLOS Part XII, Section 5 and Section 6: The relevance of provisions

Sources	**Provisions regarding international rules and national legislation**	**Provisions regarding enforcement**
Land-based	Article 207	Article 213
Sea-based: Seabed activities	Article 208	Article 214
Activities in the Area	Article 209	Article 215
By dumping	Article 210	Article 216
Ship-based	Article 211	Articles 217, 218, 219, 220, 221
Air pollution	Article 212	Article 222

Second, one of the "four pillars" of the international framework, which regulates, *inter alia*, maritime safety and security, maritime education and training, certification and watchkeeping, the protection of marine environment and the prevention of marine pollution, as well as the conditions of working and living, and other social aspects for seafarers, is the **International Convention for the Prevention of Pollution from Ships** (MARPOL). The Convention has six annexes with provisions stipulating the prevention, reduction, and control of pollution from ships by oil, noxious liquid substances in bulk, harmful substances in packaged form, sewage, garbage, and air pollution (IMO, 1973). In particular regarding marine plastic pollution, this Dissertation discusses related matters within Annex V of the Convention, which establishes regulations[20] for the prevention of pollution by garbage from ships. The Annex has three chapters and two appendixes. In detail, Chapter 1 establishes general provisions; Chapter 2 stipulates provisions regarding the verification of compliance with this Annex; and Chapter 3 establishes provisions clarifying some aspects in connection with the International Code for Ships Operating in Polar Waters (Polar Code). Moreover, Appendix I establishes criteria to classify solid bulk cargoes as harmful to the marine environment; and Appendix II establishes the form of the ship's Garbage Record Book. For the purposes of Annex V, Regulation 1 provides nineteen definitions, including, e.g., cargo residues, domestic wastes, en route, fishing gear, fixed and floating platforms, garbage, incinerator ashes, operational wastes, plastic, special area. Among these, the definition of "plastic" includes all solid materials containing one or more "high molecular mass polymers", e.g., all garbage consisting of plastic in any form, plastic garbage bags, synthetic ropes, synthetic fishing nets, and incinerator ashes from plastic wastes. This definition also mentions about the manufacture and fabrication methods, as well as the characteristics of the materials. Regarding the application of Annex V, Regulation 2 requires that all vessels shall comply with the provisions of this Annex. Regulations 3, 4, 5, and 6 establish requirements regarding the prohibition requirements and related conditions of the discharge of garbage in particular areas of concern. Also, these regulations also refer

[20] Table S5 summarizes the provisions of these regulations with the perspectives of MPP discussion.

to exceptions stipulated either in internal links (e.g., Regulation 7, Appendix I of Annex V) to this Convention or external references to other instruments.

Figure 3. *An arrangement of a port reception facility placed next to the accommodation ladder of a vessel, when mooring at the Port of Bremen* (Vuong, 2019a; Vuong, 2023c)

Regarding the port reception facilities (Fig. 3), Regulation 8 requires that adequate reception facilities shall be provided at each Party's ports and terminals for garbage reception. These facilities are required to be appropriate to the needs of those vessels disposing garbage to them, and not to cause undue delay to the operations of those vessels (Fig. 4).

Figure 4. *Delivery of ship-generated garbage to a port reception facility in the Port of Montreal* (Vuong, 2018)

It is important to highlight the amendments to Annex V pursuant to Resolution MEPC.277(70), which is adopted on 28 October, 2016 (IMO, 2016b). These amendments include a new appendix with requirements regarding harmful substances to the marine environment (HME), as well as the addition of new paragraphs or subparagraphs in connection with this new appendix, and the amendments to the existing appendix regarding the garbage record form. In detail, Appendix I of Annex V, in accordance with the classification criteria of the United Nations Globally Harmonized System of Classification and Labelling of Chemicals (GHS), lists several parameters to determine whether cargo residues of solid bulk cargoes are harmful to the marine environment. Among these criteria, and within the scope of this Dissertation, Subparagraph 7 clearly determines solid bulk cargoes, which consist of or contain, *inter alia*, synthetic polymers, plastics, rubber, or plastic feedstock pellets,

including chopped, macerated, milled, shredded, or similar materials, as of cargo residues harmful to the marine environment.

Third, by recognizing the limitation of the capacity of the sea in assimilating and rendering wastes, as well as the ability in generating natural resources, the Organization, through the **Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter**, 1972 and the 1996 Protocol to the Convention (London Convention and London Protocol), underscores the particular importance of the marine environment and the living organisms therein to humanity in particular (IMO, 1972), and the need in general for the protection of the marine environment and the promotion for the sustainable utilization and conservation of the marine resources (IMO, 1996). The Protocol to the Convention, which is based on precautionary and preventive approaches, while noting the achievement of the London Convention, aims at updating, further modernizing (IMO, n.d.b), and eventually, superseding the predecessor (pursuant to Article 23 of the latter instrument). In detail, in accordance with the Protocol's objectives, the obligations and responsibilities of the Contracting Parties include the protection and preservation of the marine environment from all sources of pollution, together with the prevention, reduction, and elimination of pollution arising from or in connection with dumping or deliberately disposing substances or materials in any of their kind, form, or description into the sea. Besides, the provisions of general obligations include the precautionary approach, the appropriate preventive measures, the "polluter-pays" principle, the requirements of not transferring or transforming damage or risk of damage, as well as the possibility of implementing more stringent measures pursuant to the Contracting Parties' legislation and international law. Strictly stipulating, pursuant to Article 4 of the Protocol, the dumping of wastes or other matter from vessels, platforms or any artificial structures at sea, and aircraft shall be prohibited, with very limited annexed exceptions. The significance of the Protocol is Annex 1, which is referred to as the "reverse list" in some literature, establishing a list of wastes or other matter that may be permitted for dumping. Notwithstanding, those listed substances or materials in Annex 1 may be prohibited from dumping by a concerned Contracting Party, provided that due

notification shall be submitted to the Organization pursuant to Article 4. Prior to issuing a dumping permit, a thorough assessment shall be performed for dumping consideration of wastes and other matter pursuant to Annex 2. The candidate wastes in question of dumping permission are subject to a screening mechanism under a national Action List, which shall be developed by each Contracting Party. One of the main purposes of the prior-permit assessment is to conduct further consideration to minimize the necessity for dumping. Besides, appropriate evaluations of waste reduction and prevention techniques (especially, at their sources), and waste management options shall be included and considered for alternatives to dumping. In the case of the existence of appropriate, safe, and environmentally sound opportunities for waste re-use, recycling, and treatment, the permit application shall be refused. In general, the input data for the prior-permit dumping assessment includes, *inter alia*, physical, chemical, and biological properties of the wastes and their constituents; their toxicity, persistence, bioaccumulation and biotransformation characteristics; together with information regarding the dump-site selection; as well as a detailed analysis and evaluation of the potential effects to and impacts on human health, the environment, other anthropogenic activities, and the future utilization. The outcome of this thorough assessment is a supporting or opposing decision for dumping permit. Further following a dumping permit, monitoring programmes, including compliance monitoring and field monitoring, are conducted. The Annex also underscores the essential requirement of reviewing the issued permits at regular intervals to consider potential feedback for purposes of the protection of human health and the marine environment.

Within the next category — **chemical-controlled** instruments, the Author reviews two conventions. Recognizing the properties of toxicity, degradation resistance, and bioaccumulation, as well as the harmful impacts of POPs on aquatic ecosystems, humans and human health, and especially to women health and the health of the future generations, the **Stockholm Convention on Persistent Organic Pollutants** (Stockholm Convention) establishes a wide range of provisions with the objectives to protect the environment and human health from those chemicals (UN, 2001). Within the context of MPP discussion, some chemicals and other harmful

substances associated with plastics and microplastics are included in the scope of this Convention, for example, *inter alia*, chemical additives, flame retardants, and plasticizers. Accordingly, measures are established for the prohibition or restriction of releases from intentional production and use, as well as from unintentional production of those chemicals, which are listed in Annex A, Annex B, and Annex C, respectively. Besides, stockpiles and wastes, which contain, consist of, or are contaminated with listed chemicals, are also required to be managed in an environmentally sound manner with purposes of reduction to elimination of releases of such chemicals.

Under the scope of the **Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal** (Basel Convention), plastic wastes are categorized as "other wastes", which required special considerations pursuant to Annex II (UN, 1989). Besides, the Conference of the Parties to the Convention adopted technical guidelines (UNEP, 2002), which deliberately extending the scope to include all polymers and plastic types. The Convention recognizes that the reduction of waste generation in terms of quantity and hazardous characteristics is the most effective way in minimizing the risk of damage to human health and the environment. In addition, the provisions also include requirements ensuring the availability of adequate disposal facilities, the environmentally sound management of wastes, and the minimization of transboundary movement of such wastes.

Within the third category — **biodiversity-oriented**, the Author reviews one instrument. Although the **Convention on Biological Diversity** (CBD) underscores the importance of the conservation of biological diversity, and expresses concerns about the significant reduction of biodiversity due to certain anthropogenic pressures, the issues of marine litter, plastics, and microplastics are not directly addressed (UN, 1992a). In this regard, further review of the instrument's updates and relevant documents is of necessity (as of the years 2020s). Nevertheless, pursuant to Article 6, relevant policies, programmes, and plans shall be integrated with the sustainable utilization and conservation of biodiversity. Within these policies, programmes, and plans, mitigation measures are established, and, therefore, the supporting relations

between the prevention of plastic pollution and the conservation of biodiversity can be demonstrated.

Although these international instruments (besides other instruments) demonstrate certain advantages and significantly contribute to the protection of the environment and the prevention of pollution, some shortcomings remain, one of which is the fragmentation of the current international regulatory framework (Ferraro & Failler, 2020).

Besides those international conventions and instruments as previously discussed, there are some agreements and instruments at regional levels, reflecting the efforts of countries, and the cooperation within their respective regions in dealing with plastic wastes in general, as well as PMP in the marine environment in particular. Within the scope of this Dissertation, the European Union (EU) legislative actions and the **Convention for the Protection of the Marine Environment of the North-East Atlantic** (OSPAR Convention) are briefly introduced. Encountering similar situation as elsewhere in the world, on beaches in the Europe, plastics account for more than 80% of total quantity of marine litter items collected; whereas, single-use plastics make up approximately 50% of that quantity (Halleux, 2019). Earlier, the European Parliament and the Council of the European Union (2008) had established Marine Strategy Framework Directive for the achievement and maintenance of a "good environmental status" in the marine environment, which is determined by qualitative descriptors. Among these criteria, the quantities and properties of marine litter are required not to cause harm to the coastal areas and the marine environment (Descriptor 10). In 2018, a public consultation was carried out by the European Commission, showing the considerations of the majority of respondents that tackling marine litter and single-use plastics are of urgent and necessary concerns (Halleux, 2019). In the same year, the Commission adopted their strategy for plastics in a circular economy, which includes a wide range of measures for implementation (European Commission, 2018); for instance, *inter alia*, improving plastic recycling (via product design, waste separation and collection), curbing littering, plastic wastes, and microplastic pollution, improving mapping and monitoring of marine litter. Further, the European Parliament

and the Council of the European Union (2019) adopted Directive 2019/904 on the prevention and reduction of the impacts from certain plastic products on the environment in general, the aquatic environment and the human health in particular, as well as on the promotion of the transition to a circular economy. The scope of the Directive covers certain plastic products, which are listed in its Annex, as well as oxo-degradable plastics and fishing gear containing plastic materials. In detail, pursuant to the Directive's articles, not only some single-use plastic products (e.g., cups for beverages, food containers) are under requirements for consumption reduction, but also certain single-use plastic products and products made from oxo-degradable plastics are prohibited on placing on the market; for instance, cups, food and beverage containers made from EPS, drinking straws, plates, cutlery, cotton bud sticks. Besides, specific requirements regarding product design, marking, extended producer responsibility, separation and collection, and awareness raising, are also established for certain single-use plastic products.

Similarly, recognizing the foremost importance of the marine environment, and the flora and fauna therein of the North-East Atlantic, as well as the significance of coordinated protection of the regions, the EU and other 15 Contracting Parties to the OSPAR Convention agreed on and established provisions with the general obligations of the prevention and elimination of marine pollution, considering all sources of pollution, for the purposes of protecting human health, conserving marine ecosystems, and restoring severely affected marine areas (OSPAR, 1992). Especially, the Convention recognizes the possible desire in adopting "more stringent measures" at regional level in comparison with international counterparts (OSPAR, 1992). The geographic scope of the Convention covers certain parts of the Arctic Ocean and the Atlantic Ocean, including, *inter alia*, the North Sea, the Baltic Sea, and the Mediterranean Sea. Within these regions, measures for the prevention and elimination of pollution are applied to pollution from land-based sources, dumpling or incineration activities in the maritime areas, from off-shore and other sources, of which the details are promulgated in the Convention's Annex I, Annex II, and Annex II, respectively. Generally speaking, any incinerations or dumping of wastes or other matters in the

maritime areas or from off-shore activities are prohibited. In addition to the prohibition provisions, there are two main principles, which are underscored by the Convention for application by the Contracting Parties; namely, the precautionary principle (through preventive measures), and the "polluter-pay" principle. Besides, the Convention also stipulates provisions regarding the reduction and elimination of toxic, persistent, and harmful substances, which originate from land-based sources, and possibly bio-accumulate in the marine environment. Furthermore, the instrument also promulgates specific provisions for the protection and conservation of the biological diversity and the ecosystems in the maritime areas, considering CBD. The purposes of these two areas of legislation (i.e., the EU legislative actions in tackling single-use plastics, and the OSPAR Convention), primarily converge at the protection of the marine environment and human health. The Union's instruments aim at the target of a circular economy, in which innovative and sustainable consumption and production patterns are promoted; whereas, the regional instrument is ambitious in achieving the harmony management of maritime areas and human activities, both for the legitimate utilization of the sea, and the needs of the present and the future generations.

With regard to other relevant IMO's instruments and strategies, the Organization's works can link to the United Nations Sustainable Development Goals (SDG). Although the Organization's mandates mainly integrate to SDG 14 and its targets, other IMO's works also contribute to the achievement of these 17 global goals and their 169 respective targets (IMO, 2017; IMO, 2019b; IMO, n.d.a). For instance, the IMO's regulations ensure safe, secure, efficient, and clean shipping on clean ocean through implementing a wide range of conventions and instruments; for instance, *inter alia*, SOLAS and MARPOL (linkages to SDG 14, SDG 13, SDG 7, and SDG 6), and STCW together with MLC (linkages to SDG 4, SDG 5, and SDG 8). Besides, the IMO's Model course 1.38 – Marine environmental awareness (2011 Edition) also addresses the importance of human performance and their roles in the protection of the marine environment, as well as the prevention of marine pollution (IMO, 2011). Further in these regards, reference can be conducted to the Supplement materials

(Appendix D), which briefly reviews several relevant IMO's instruments, including, SOLAS, MARPOL, STCW, III Code, ISM Code, Polar Code, and MLC.

CHAPTER 4
MARINE PLASTIC POLLUTION: POTENTIAL SOLUTIONS

Recognizing the "serious environmental problem at a global scale" of plastic pollution in general, and marine litter (including plastics and microplastics) in particular (hereinafter referred to as "plastic pollution", which including in the marine environment), the UNEA of the UNEP discusses the related concerns and adopts a wide range of resolutions (UNEP, 2022). Herein, several resolutions[21] adopted by the Assembly are reviewed (UNEP, 2019a; UNEP, 2019b; UNEP, 2019c; UNEP, 2022). Through studying the development of these resolutions (from 2014 to 2022) in terms of their included concerns and relevant issues, the possible shape, structure, and contents of the potential solutions in tackling plastic pollution can be discussed, taking into consideration the aforementioned discussions regarding the current states, scientific evidence, current policies and strategies from the UN, the IMO, and the EU, as well as the recommendations from many researchers.

First of all, due to the global, diverse, and complex nature of plastic pollution, the development and adoption of "an international legally binding instrument" to tackle this serious environmental problem are of particular importance (Ferraro & Failler, 2020; UNEP, 2022). In general, this international convention on plastic pollution will address plastic inputs from all sources and throughout their whole life cycle, while considering specific national capabilities and circumstances. The purposes of this new instrument may include, *inter alia*, the protection and preservation of the environment and the nature, all living organisms therein, humans and human health, and the prevention, reduction, control, and ultimately elimination of plastic pollution in the environment, as well as safeguarding social aspects and other anthropogenic activities. It is important to note and recognize the on-going works,

[21] UNEP/EA.1/Res.6: Marine plastic debris and microplastics (2014), UNEP/EA.2/Res.11: Marine plastic litter and microplastics (2016), UNEP/EA.3/Res.7: Marine litter and microplastics (2017), UNEP/EA.4/Res.6: Marine plastic litter and microplastics (2019), and UNEP/EA.5/Res.14: End plastic pollution: Towards an international legally binding instrument (2022); and UNEP/EA.4/Res.7: Environmentally sound management of waste (2019), UNEP/EA.4/Res.9: Addressing single-use plastic products pollution (2019).

efforts, and contributions from many relevant regional and international conventions and instruments, (for instance, *inter alia*, UNCLOS, MARPOL, LC/LP, Basel Convention, Stockholm Convention, CBD, UNFCCC) in dealing with plastic pollution within their respective mandates. Considering these, the new instrument's provisions will be established in comprehensive and complementarity approaches. In other words, the new plastic treaty will consider and address plastic pollution throughout their whole life cycle (for instance, *inter alia*, from resource efficiency, product design, manufacture, transport, to all sectors of the supply chain, retail, consumers, disposal, and waste management), with due regards to respective mandates of other conventions and instruments, in order to avoid duplication. One of the main features of the new instrument is its flexibility, containing both mandatory provisions and voluntary part (or recommended guidelines).

Second, the new instrument's objectives are clearly identified to align with the aforementioned purposes, with due considerations for the participation and engagement from all stakeholders. Besides, it is of particular importance to establish common definitions and terminology regarding plastics and plastic pollution (e.g., size, measurement, and methodologies), together with harmonized standards, methods, and indicators for monitoring, reporting, and assessment of this global problem (Bonanno & Orlando-Bonaca, 2022).

Third, as this global problem is recognized with a wide, diverse, and complex nature, all dimensions and factors are to be considered, addressed, and included; for instance, all sources and pathways of plastic pollution, all of their negative impacts throughout their whole life cycle, and the full participation and engagement from all stakeholders (as mentioned). Certainly, all sources and pathways of plastic pollution, including, *inter alia*, land-, sea-, and ship-based sources, freshwater pathways, are to be addressed and included in the mandates of this new instrument. Besides, all negative impacts arising from or in connection with plastic pollution are to be addressed and included in order to fully tackle the problem; for instance, impacts on, *inter alia*, the environment (including the marine environment), its biodiversity, ecosystem services, and natural resources therein, anthropogenic activities, humans and human health, the

(marine) food chains and food safety, the distribution and spreading of harmful organisms and invasive species through plastic debris and microplastics. Furthermore, issues regarding chemical additives and harmful substances, e.g., POPs, associated with plastics and microplastics are to be addressed and included in the new instrument's provisions. With this regard, the importance of transparency of plastic production, plastic products, and their full-life-cycle impacts (in terms of chemicals and their adverse effects) is underscored with the participation and engagement from the private sector (Almroth & Eggert, 2019). In addition, the link between plastics and plastic products (with the perspectives of their full life cycle) versus climate change is to be addressed within the mandates of this new instrument; and *vice versa*, climate change, climate-related extreme events (e.g., storms and flooding), and their exacerbation in widespread distribution and accumulation of plastic pollution, are to be considered (Ford et al., 2022).

Fourth, based on the reviewed resolutions of the UNEA of the UNEP, the inputs of plastic wastes and plastic pollution in or into the environment can be divided into three categories; namely, the past inputs resulting in existing debris and litter, the present inputs (from any releases other than accidental releases, and from accidental releases), and the future potentially preventable, reduceable, and controllable inputs. For each category of inputs, appropriate mitigation measures are to be applied. In general, the UNEA of the UNEP, in agreement with many researchers (Jambeck et al., 2015;), continuously underscores the importance of environmentally sound management of waste, which can be applied for all inputs. In detail, the past inputs can be handled by environmentally sound clean-up, collection, and recycle. Besides, for further effectiveness, hotspots of plastic waste accumulation should be identified for prioritization of clean-up activities (Thiel et al., 2018). Regarding the present inputs from any releases other than accidental releases, besides environmentally sound management of waste, plastic waste prevention and reduction are to be promoted (Jambeck et al., 2015) and included in the new instrument. Some measures and practices include, *inter alia*, further improvement of the current waste management practices, provision of adequate port reception facilities, and especially, sustainable

production and consumption, resource efficiency, extended producer responsibility schemes, and circular economy. There are several models of practices to support the circular economy; for instance, 3R (Clean Authority of Tokyo, 2023; UN, 2012), and 12R (Bonanno & Orlando-Bonaca, 2022). Recognizing the achievements from those mentioned models, and considering the capabilities and available resources at each level (ranging from individual, community, local, regional, to industrial, and beyond), the Author proposes a general and universal approach: $eR = eX$, as follows:

$$\begin{cases} eR = eX = \{R_i = X_i |\ i = \overline{1; e}\ and\ R_i = X_i \in \mathbb{R}\} \\ eR = eX \subset Circular\ Economy \end{cases} \quad (5)$$

where:

$e \in [1; +\infty)$;

$i = \overline{1; e}$;

$\mathbb{R} =$ {Reduce, Reuse, Recycle, Re-sort, Repair, Refill, Report, Replace, Reinnovate, Remove, Regulate, Read, Research, Prevent, Control, Save, Economize, Cooperate, Facilitate, Implement ...}.

Figure 5. *A waste separating station in the workplace of the WMU's Neptune Building, Slottsgatan 2, 211-21 Malmö, Sweden* (Vuong, 2023h)

Consequently, every individual person or larger settings can choose their contributing actions from $1R$ (or $1X$) to nR (or nX), depending on their appropriate and available means. The responsibilities, awareness, commitments, attitudes, and motivations of individuals and organizations at all levels (i.e., all stakeholders, including, the general public, scientific communities, industries, and policy-makers) significantly support the process and determine their contributions, of which the affirmation converges with the preamble of the ISM Code (IMO, 2018b). These commitments can be transformed into actions in our houses, our workplaces (Fig. 5), and local communities (Fig. 6), and beyond.

Figure 6. *A recycling station in the local supermarket ICA Kvantum Malmborgs Caroli in Malmö, Sweden* (Vuong, 2023f)

Critically important, it is of necessary to consider the reduction and elimination of the use of primary microplastics and microbeads in manufacturing. In terms of the accidental releases of plastics and microplastics contributing to the present inputs, the measures focus on the prevention of losses of primary microplastics (e.g., plastic feedstock pellets), as well as the prevention of spillage into the environment during manufacture and transport stages (Kurniawan & Imron, 2019). With regard to the future inputs, further development and innovation are to be fostered (UNEP, 2019; UNEP, 2022), including, e.g., environmentally sound alternatives both in product design and materials, reduction of plastic packaging, and reduction of secondary microplastics (through fragmentation and degradation).

Fifth, action plans are required to be developed, implemented, and periodically updated at national level and regional level (where applicable). *Sixth*, cooperation at all levels is another important element of the new instrument, especially in terms of capacity building, technical assistance, and support mechanism for developing countries, least developed countries, and small island developing countries, or countries with economies in transition to ensure effective implementation (Jambeck et al., 2015). *Seventh*, other important elements of the successful implementation of the new instrument include the awareness and engagement of all stakeholders (Bonanno & Orlando-Bonaca, 2022). The new provisions will include requirements regarding public information, awareness raising, and education. Besides, the promotion of the change towards sustainability in consumer and producer behaviors should be included in the awareness-raising programmes. *Eighth*, the new instrument itself, the provisions and measures therein will be periodically assessed and evaluated in terms of its objectives' achievement and effectiveness. Besides, other provisions may include aspects regarding research, knowledge sharing, information exchange, and technology, as well as reporting requirements.

With the full, responsible, and constructive participation and engagement from all stakeholders (Fig. 7), including the general public, industries, scientists, and policy-makers, who are equipped with sufficient knowledge and adequate awareness, in synergies with the effectiveness of the new instrument, the short-term and long-term

goals of significant prevention, reduction, control, and gradual elimination of plastic pollution can be achieved.

Figure 7. *A waste separation station in a local community in Malmö, Sweden* (Vuong, 2023e)

CHAPTER 5
DISCUSSION

Following the sections of literature review and potential solutions, Chapter 5 further discusses four aspects: 1. Awareness raising and cooperation among all stakeholders; 2. The interconnections between maritime safety, human element, and MPP; 3. The fundamental relations between climate change and MPP; and 4. Environmentally sound management of waste.

5.1 Awareness raising and cooperation among all stakeholders

Obviously, not only the marine environment and marine wildlife, but also humans and human health are affected by plastic pollution in general and MPP in particular; for instance, through the accumulation of chemical additives inside humans following the consumption of contaminated products, e.g., seafoods and sea products (Bonanno & Orlando-Bonaca, 2022; Kurniawan et al., 2021). Nevertheless, according to Kurniawan et al. (2021), the public awareness of this issue is still low; whereas, UNEP (2014) argued that the awareness of the global community has been improved through the media reports and the works of non-governmental organizations (NGO). Many researchers agree on or provide support to the efforts in awareness raising among all stakeholders and the community involvement (Fig. 8) at all levels (Ford et al., 2022; Kurniawan et al., 2021; Thiel et al., 2018). These involvement and engagement can originate from individual to industrial levels (Ford et al., 2022); for instance, changes in consumers' habits, especially in particular communities, where disposable plastic packaging is widely used (Fok & Cheung, 2015). Besides, a shift from a linear production-consumption pattern to a circular approach (or a circular economy, with responsible and sustainable production and consumption), which links to SDG 12, emerges as one of the integrated solutions to tackle the problematic issues of plastic pollution (Bonanno & Orlando-Bonaca, 2022; Ford et al., 2022; UN, 2015; UN, 2021b).

Figure 8. *A recycling station in a public area in Malmö, Sweden* (Vuong, 2023g)

5.2 Maritime safety, Human element, and MPP: Relations and relevances

The maritime safety and the prevention and control of marine pollution from vessels are, *inter alia*, two of the main concerned mandates within the purposes of the International Maritime Organization (IMO, 1948). Despite the requirements of "the highest practicable standards" in those matters (IMO, 1948) and their current works, IMO (2008) reaffirmed the fact of continuous occurrence of maritime casualties, which result in not only the losses of lives and properties, but also damages to the marine environment. Different types of marine pollution arising from or in connection with maritime casualties include oil spills, chemical spills, losses of cargoes, and losses of containers or container vessels (ITOPF, 2023; Jambeck et al., 2015), the consequences of which, eventually link and contribute to plastic pollution. For instance, response operations and shoreline clean-up of oil spills often generate a large quantity of waste, possibly over many times the volume of the original spills (IMO,

2018a; ITOPF, 2023), including, e.g., contaminated debris, response sorbents (Fig. 9), and personal protective equipment (PPE), materials of which contain or consist of plastics. Whereas, chemical spills not only affect the water surface and water column, but also sink to the seabed, then accumulate and contaminate the bottom sediment; consequently, these substances, especially some organic compounds, may enter the food chain (via marine species of the lower trophic levels) and travel up to the top consumers (ITOPF, 2023). In terms of cargo and container losses, besides the packaged cargoes themselves, packaging and dunnage materials associated thereof, the spillage of plastic pellets (also known as nurdles in some literature, which are feedstocks for manufacture of plastic products) currently receive particular attentions, due to their ubiquity in the marine environment, their potential to absorb POPs and act as transferring vector in the marine food webs, and their widespread behaviors over large distance upon spilling. These mentioned features not only harmfully affect marine wildlife and human health, but also create difficult challenges in locating and removing this particular type of microplastic particles in the marine environment, and in effectively performing shoreline clean-up (ITOPF, 2023).

Figure 9. *An example of sorbent materials equipped in a Shipboard Oil Pollution Emergency Plan (SOPEP)* (Vuong, 2019b)

Fig. 10 illustrates the contributing relations and conceptual intersections between three main aspects regarding maritime safety, human element, and the marine environment, with MPP at the center of intersections, while distinguishing accidental pollution arising from maritime casualties versus violations occurring from intentional or operational discharges.

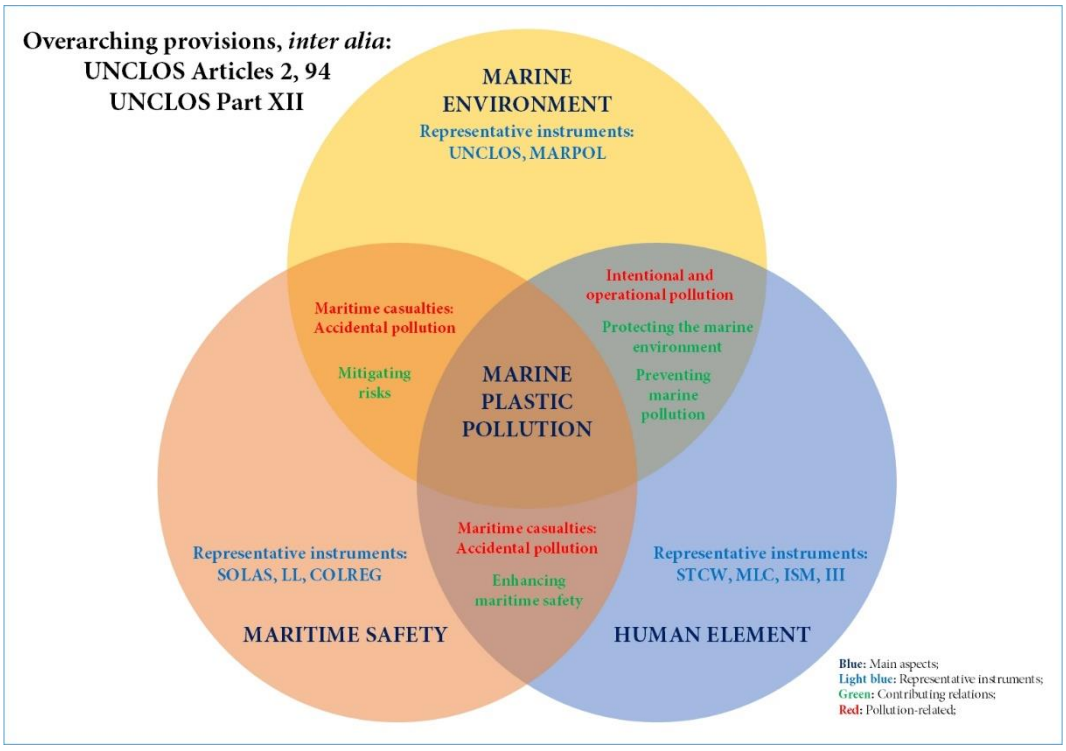

Figure 10. *Maritime safety, Human element, and MPP: Relations and relevances*

In order to examine the illustration, it is recommended to refer to the relevant international instruments and strategies. The interconnected relations between the maritime safety, the human element, and the protection of the marine environment in general and MPP in particular (hereinafter referred to as "the interconnected relations") can be analyzed from several starting viewpoints; namely, UNCLOS provisions, the IMO's procedures for identification of safety issues, and the featured example of the Polar Code.

In the first place, UNCLOS Article 94 stipulates the duties of flag States, one of which is to ensure maritime safety by establishing measures applied for vessels registered under their flag. Those measures include, *inter alia*, safety-related requirements (the vessels' construction, equipment, and seaworthiness) and human-element-related requirements (the manning levels, working conditions, training and competence of seafarers with regard to maritime safety, and especially, the prevention, reduction, and control of marine pollution). Herein, the Convention identifies the seaworthiness of vessels as part of maritime safety. Further in connection with this matter, UNCLOS highlights the particular importance of maintaining the seaworthiness of vessels for the purpose of preventing risks of damages to the marine environment (pursuant to Article 219). Besides, other UNCLOS provisions also address safety-related measures in connection with the protection of the marine environment. For instance, "routeing systems" are to be promoted for adoption as deemed appropriate pursuant to Article 211(1). These systems, one function of which, *inter alia*, is to reduce or minimize the risk of maritime casualties, accidents, and incidents (IMO, 1974), and therefore, contribute to maritime safety and the protection of the marine environment not only to the nearest coastline, but also, to other related interests of the coastal States. Furthermore, UNCLOS also emphasizes the importance of "prompt notification" to coastal States, and enforcement measures to prevent pollution to the marine environment and further escalation of major harmful consequences arising from or in connection with maritime casualties, including, *inter alia*, collision, stranding, navigational incidents, and other shipboard occurrences (pursuant to Article 211(7) and Article 221).

Second, similar to the risk-based approach in terms of "routeing systems", there are two procedures adopted at the IMO for identifying safety issues (Vuong, 2023a); namely, marine casualty investigation (MCI) and Formal Safety Assessment (FSA). The IMO (2013c) defines safety issues as causal factors or unsafe conditions, which contribute to a casualty event or worsen the consequence thereafter. In addition, safety deficiencies are safety issues, existing defenses of which are inadequate or missing, and fail to cover risks thereof. Regarding MCI, the IMO (2008, 2013c) reaffirms the

need to identify root causes of marine casualty through investigation following timely and accurate reporting, which can significantly increase the awareness of the public and industry; thus, resulting in enhancing maritime safety and the prevention of marine pollution (Fig. 11). To emphasize, the MCI identifies not only the direct causal factors related to the casualty events, but also safety issues and deficiencies, which are usually located remotely from the accident site, e.g., in the case of major management errors and poor management practices (IMO, 2018b). In other words, the whole chain of responsibilities, ranging from management level, e.g., policies, regulations, effectiveness of safety management system, risk assessment and management, to operation level, e.g., mechanical and human factors, is thoroughly analyzed. As a matter of fact, MCI is a reactive procedure following an accident or incident to identify causal factors; whereas, FSA is a proactive procedure to address safety issues, which will greatly contribute to the evaluation of the existing and new regulations in maritime safety and environment protection (IMO, 2018a). It is important to note that, the process of FSA also incorporates the human element, which is recognized as either an important causal factor, or a contributor of casualty avoidance. In general, the FSA procedure underscores the complex feature of risks via their causal chains, which start from causal factors, and, followed in chronological sequence by failure, circumstance, accident, and consequences. Besides the causal chains, the risk levels can be expressed through the view point of risk assessment in general, and the basic risk equation in particular, which depends on the probability or consequence of the event, or both (IMO, 2018a). Based on either the causal chains or the risk level equation, measures to reduce risks can be aimed at accident prevention (through failure effect mitigation and circumstance alleviation), or consequence mitigation; and in particular, through better design (safety-related), organizational procedures and polices (management-related), and training (human-element-related), reducing the frequency of failures (or the probability of occurrence); thus, risk mitigation can be achieved (IMO, 2018a).

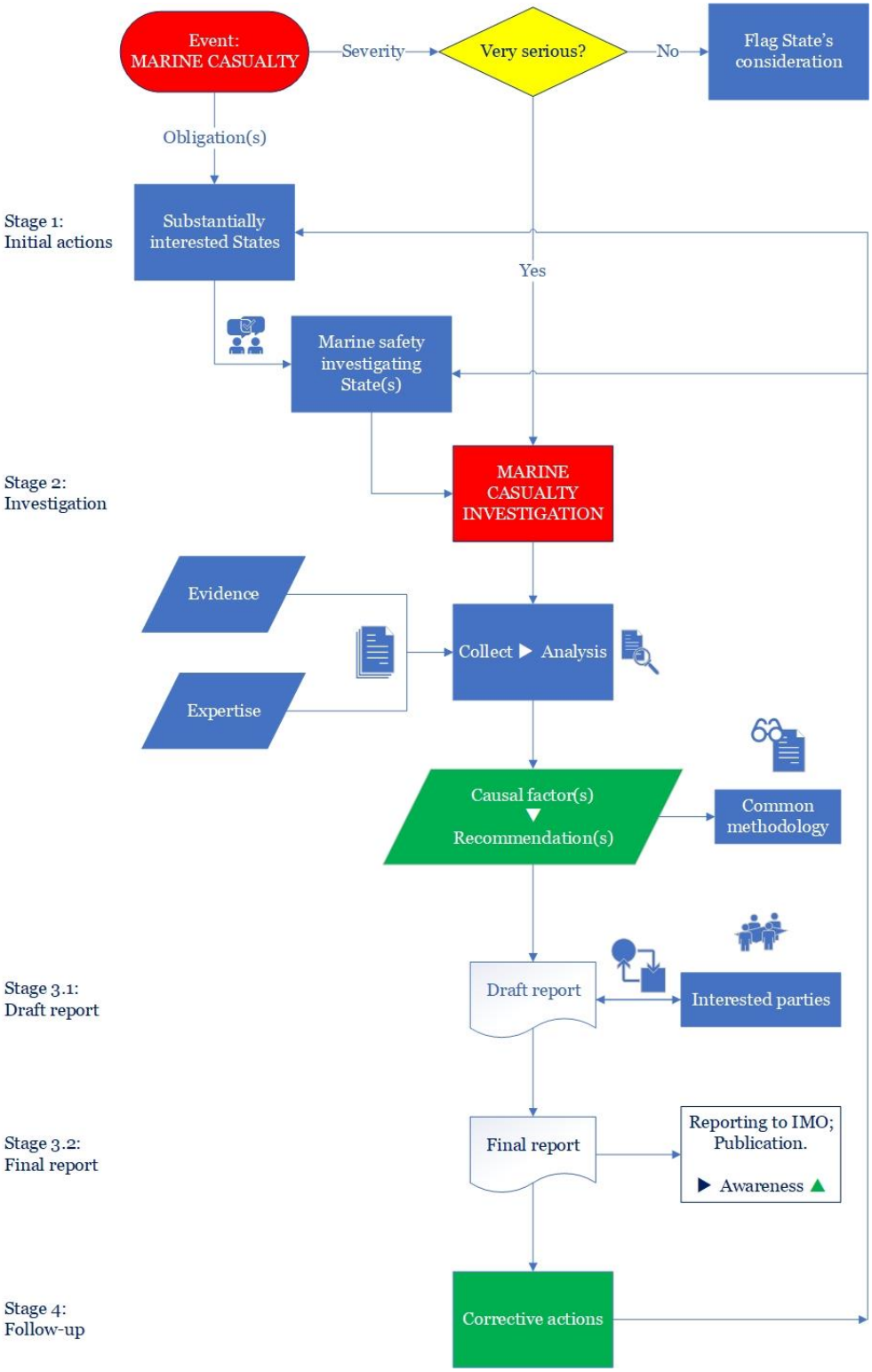

Figure 11. *MCI process*

Third, the featured example of the Polar Code (IMO, 2016a) clearly addresses the interconnected relations. The flexible structure with risk-based and holistic approach of the instrument comprises of both mandatory provisions and recommendatory measures, covering a full range of three dimensions; namely, maritime safety (design, construction, equipment), environmental protection, and human element (operational aspects, training). The risk-based approach of the development and establishment of this Code can be explained utilizing the aforementioned discussion regarding causal chains and risk levels. Upon operations in "the pristine environments" of the polar regions, and due to the current increase of traffic therein, the distinguished features of the polar waters, e.g., *inter alia*, the remote characteristics, vulnerability, and potentially harsh conditions, there will be additional demands on vessels, their systems and operational matters, and especially, the protection of the polar environment. These demands originate from a wide range of particular hazards of and associated with the waters and regions surrounding two poles, including, *inter alia*, circumstance-related (ice conditions, low temperature, extended periods of daylight and darkness, high latitude, remoteness, navigational hazards, rapid change and severity of polar weather), human-element-related (the extent of crew experience), operation-related (search and rescue readiness, availability of response options and means), and environment-related (the sensitivity of the polar environment, its longer period of restoration), as well as the complex interconnected and consequential impacts from these primarily recognized hazards. The risk levels, consequently, may increase due to the elevation of either the probability of occurrences, or the severity of the consequences, or both, which are beyond the existing requirements of the SOLAS, MARPOL, and other relevant IMO's mandatory instruments (IMO, 2016a).

The Organization recognizes the human element as "a complex multi-dimensional issue" covering the entire scope of the shipping industry and beyond, and involving many stakeholders, either ship-based or shore-based, including, *inter alia*, regulatory bodies and legislators, shore-based managers and personnel, seafarers, shipyards, other private-sector organizations and parties (IMO, 2003). In fact, the

maritime safety and security, and the protection of the marine environment are affected by these stakeholders, as well as the complex features of the human element. The Organization, therefore, underscores the importance of the need for cooperation in addressing the human element among those stakeholders, with the vision to improve the overall performances; thus, in the result, the maritime safety and security, the protection of the marine environment, and the prevention of marine pollution in general, and the prevention of MPP in particular, can be significantly enhanced (IMO, 2003; Vuong, 2023b). Specifically, the Organization's strategy (IMO, 2006) emphasizes the importance as "a critical line of defence" of the shipping companies in general, which is demonstrated through, *inter alia*, the ISM Code. Besides the obligations and responsibilities of those ship owners, managers, or operators in compliance with mandatory instruments, it is of particular importance to underscore the on-going works and efforts of the Organization in supporting those entities with regard to the enhancement of the environmental consciousness and the maritime safety and security culture. In terms of seafarers and their contributions, their crucial, direct, and prominent role is acknowledged in maritime safety, security, and marine environment protection in general, and the prevention of maritime casualties in particular (together with other stakeholders' contributions). Further on the environmental awareness, the Organization establishes an action plan (IMO, 2018d) committing to equip seafarers with knowledge and awareness in matters of, *inter alia*, the importance of marine ecosystems, and the sustainability in the shipping industry. Also, maritime education and training is recognized as an effective way to achieve the action plan's goals, simultaneously with the cooperation and contribution from the Member States in terms of their information, knowledge, and experience sharing. Pursuant to the strategic direction SD 6 – Addressing the human element, which is underscored as "a key element" and "an overarching principle" for the Organization, during the process of developing and amending provisions, those aspects are to be considered, *inter alia*, MET, safe manning, fatigue management, operational safety and security, environmental protection, fair treatment of seafarers, as well as the women empowerment (IMO, 2021b).

5.3 Climate change and MPP: The fundamental relations

There are no two identical perspectives. Indeed, the perspectives on the relations between climate change and plastic pollution also vary, from researcher to researcher, and from institution to institution. Ford et al. (2022) underscored at least two angles towards this aspect; namely, either being treated as two separated issues or competing opponents, and actually linked as fundamental relations. The fundamental links between those two global environmental crises can be examined from the viewpoints of the United Nations Framework Convention on Climate Change (UNFCCC). The Convention underscores the "common concern of humankind" in terms of climate change and its adverse impacts (UN, 1992c). In detail, the concentration of GHG emission in the atmosphere has substantially increased due to many anthropogenic activities; thus, enhancing greenhouse effect, and resulting in the global warming; consequently, causing adverse effects on the environment and humans. Accordingly, the fundamental relations between marine plastic pollution in particular (and plastic pollution in general in a wider scope) versus climate change and their adverse effects can be examined in two opposite directions. The forward direction shows the negative contribution to GHG emission throughout the whole life cycle of plastic products, from the beginning of their manufacture to the end-of-life disposals and treatments (Ford et al., 2022; OECD, 2023). The backward direction shows adverse effects from climate change and climate-related extreme weather conditions, exacerbating widespread distribution and accumulation of plastic debris and microplastics in the environment (Ford et al., 2022); thus, further deteriorating the problematic issues of MPP. Both these two global environmental crises, their interactions, and exacerbations affect vulnerable species and destabilize sensitive ecosystems, e.g., bio-diverse habitats of coral reefs, as well as increase and facilitate the mobility of invasive species (Ford et al., 2022). These interconnections and opposite contributing relations can be considered in development of integrated plans for climate change adaptation for coastal areas, which are affected by floods, for instance (pursuant to Article 4). Taking these into account, the Convention underscores the importance of considering all GHG emissions and their respective contributions in terms of the establishment of response

strategies to, ultimately, protect the climate system for the present and the future generations, which can be achieved through two stages: the first of which is to stabilize the atmospheric concentration of GHG emissions up to a certain level that allows the second stage of the prevention of harmful anthropogenic impacts on the climate system.

5.4 Environmentally sound management of waste

According to UNEA of the UNEP, management of waste in general and plastic waste in particular is not effective in all of their Member States, despite of the primary environmental concern of solid waste (UNEP, 2019). In terms of these shortcomings, assuming no improvements in waste management infrastructure, Jambeck et al. (2015) predicted the enormous increase by an order of magnitude of plastic waste accumulation from land-based sources to the oceans. Recognizing the benefits that an environmentally sound waste management policy contributes to the reduction of GHG emissions, the improvement of human health, and the protection of the marine environment, the Assembly underscores the promotion of integrated approaches in waste management (UNEP, 2019), which include, *inter alia*, sustainable consumption and production, circular economy, the removal of hazardous chemicals from waste before processing, reuse and recycling, as well as prevention and reduction of wastes at their sources. Similarly, the Clean Authority of Tokyo (2021) highlights the importance of exercising 3R practice (reduce, reuse, and recycle); noting that the first step — waste reduction is the most important since recycling may not be applicable to all types of wastes (Fig. 12). Besides, other matters regarding the minimization of packaging materials, the phasing out of certain single-use plastic products, the improvement of product alternative materials, design, and manufacture throughout their whole life cycle, are encouraged for promotion and development, with the engagement from all stakeholders, including, *inter alia*, the private sector, waste producers, local authorities, civil society, and public (UNEP, 2019a; UNEP, 2019b).

Figure 12. *Municipal waste being separated and processed at a treatment plant of Tokyo Metropolitan Government Bureau of Environment, in Tokyo, Japan* (Vuong, 2023i)

CHAPTER 6
SUMMARY AND CONCLUSIONS

As a matter of fact, the ocean and the marine ecosystems provide the global community and the wildlife (Fig. 13) with various and priceless values (UN, 2021a). Nevertheless, human activities have emerged as the main threats to the natural environment and the marine ecosystems (UN, 2021a). These anthropogenic pressures, about which perspectives from different researchers, institutions, and organizations are different. Through the scholarly and institutional materials, which are listed in the References, the Author has further recognized and understood these anthropogenic impacts, including MPP in particular, and plastic and microplastic pollution in general, on the environments, the marine ecosystems, and even humans.

Ultimately, the Author has conducted Dissertation research on the current state of MPP, its scientific evidence, knowledge gaps, challenges, together with an analysis on the current policies in tackling MPP, as well as discussions on potential solutions and cross-section issues.

Many researchers agree on or provide supports to the fact that plastic and microplastic pollution is a complex, extensive, and multidimensional environmental crisis, with no simple solution (Bonanno & Orlando-Bonaca, 2022; Schmaltz et al., 2020), but rather "plausible solutions", which require concerted efforts and collaborative cooperation from all stakeholders (all involved parties, including general public, scientific communities, industries, and policy-makers) to effectively tackle this global challenge, to prevent, reduce, control, and gradually eliminate plastic and microplastic pollution. Besides, awareness raising and environmental education are also important among all stakeholders. These are vital as responsibilities, commitments, and engaging and involving actions from each individual to industry levels are key factors (Bonanno & Orlando-Bonaca, 2022; Schmaltz et al., 2020) for the successful implementation and enforcement of any regulations (Vuong, 2018).

Further studies and researches are, therefore, of particular necessity to expand the current body of knowledge, as well as to bridge the knowledge gaps, in terms of

major sources and pathways of plastic and microplastic pollution, their physical and toxicological impacts on the marine environment and marine wildlife, humans and human health, other anthropogenic activities, as well as connections with certain anthropogenic pressures and climate change.

Figure 13. *Seabirds foraging in the Archipelago of Gothenburg, Sweden* (Vuong, 2023j)

In conclusion, it is important for each individual and entity of us to be aware that whenever we dispose (or throw away, litter, or discharge over board) any garbage or plastic waste in particular, into the nearest environment (or rivers, aquatic environment, or the sea), these plastics and wastes (including primary and secondary microplastics, e.g., single-use plastic items, cigarette filters) may reach some remote locations and islands (Bonanno & Orlando-Bonaca, 2022) and elsewhere of the Earth, or even be washed back to the shorelines of these particular individual and entity's areas of origin, or may even return back as daily products on our dining tables; and

ultimately, may “reach the human gut” (UEG, 2018). The presence of microplastic particles in human body is of particular concern, especially to patients with gastrointestinal diseases. Further, the smallest microplastic fragments may enter the blood streams and lymphatic system, and in some worse cases, are even capable of reaching the liver (UEG, 2018).

[End of the Chapters.]

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Appendix A

MARINE PLASTIC POLLUTION: SCIENTIFIC EVIDENCE

Table S1

Marine plastic pollution: Scientific evidence

Category	Geography area	Reported case, Evidence
MARINE LIFE		
Marine biota	Spain	Marine biota along 200 km coastline of Asturias, central Bay of Biscay, Spain is affected by beached anthropogenic litter. The research showed that plastics make up the highest share of anthropogenic litter at sampled beaches. Various rafting biota on fouled litter items are non-native and invasive, including species of oyster, bivalves, gastropods, polychaetes, acorn barnacles, goose barnacles, bryozoan colonies, hydrozoan colonies, and snail. The majority of litter items found on the sampled beaches, due to their small fragments, were difficult to be attributed to their sources. The research noted that fishing and aquaculture activities are important sources of beached litter. (Rech et al., 2018)
	Southeast Pacific	An extensive review of scholarly literature, including published studies, conference proceedings, photographic records, unpublished data, was carried out by the researchers. The survey underscores that

anthropogenic marine debris in the Southeast Pacific originates from land-based sources, such as coastal and inland populations, activities at beaches, as well as from sea-based sources, including, *inter alia*, aquaculture and fisheries. The research reviewed 97 documented vertebrate species in the studied areas, which have interactions with plastics, suffering from either ingestion or entanglement, or both. The findings include 5 species of marine turtles, 19 species of marine mammals, 20 species of fishes, and 53 species of seabirds. Among those surveyed animals, marine turtles suffer the most from plastic-related pressures. Regarding fishes, planktivorous fish is vulnerable to plastic ingestion due to their visual-oriented feeding behavior. Likewise, many seabird species also suffer from those negative impacts; especially, the kelp gull species *Larus dominicanus*. Particularly, plastics when being used for nesting may affect both the chicks and the adult individuals due to, *inter alia*, alteration of thermal properties, as well as risk of entanglement. In terms of marine mammals, many reported cases of entanglement are documented, including, *inter alia*, large baleen whales, pinnipeds, toothed whales, dolphins, porpoises, sea otters, and sea lions. The observed cases of entanglement are mostly related to fishing gear; with the similar scenarios: upon swimming and diving through the mesh, those animals become entangled; shortly afterwards, they are suffocated due to the inability of escaping, and finally,

		drowning. The researchers called for actions to mitigate those negative impacts from anthropogenic pressures on marine vertebrates in particular, including mapping of MPP hotspots for resource prioritization and conservation measure implementation, together with environmental education and public involvement, as well as effective strategy for reduction of plastic waste. (Thiel et al., 2018)
Fish	California (USA)	Northern anchovy, an abundant forage fish and a critical prey resource, ingests plastics in natural conditions due to misidentification of plastics as their prey. The evidence suggests that the chemical signature or odors of plastic debris may be attractive to marine consumers. In detail, many species of fish localize food by a common mechanism of olfaction. When foraging, the anchovy is stimulated by odors associated with bio-fouled plastic debris, which explains why certain marine consumers mistake plastics for food. (Savoca et al., 2017)
	Samples collected from Indo-Pacific coral reefs; Laboratory experiments.	An aquarium-based experiment showed evidence that juveniles of a planktivorous fish species *Acanthochromis polyacanthus* are exposed to microplastics. In detail, plastic fragments were found in gastrointestinal tract of approximately 20% of fish. Besides, the number of plastic particles in the gastrointestinal tract of the fish were strongly dependent on particle size. The smaller size of plastic

		particles was more frequently consumed than the larger size, as the ability of the fish to distinguish between food and plastic particles decreases. As plastics continually fragment in the marine environment into smaller particles, the planktivorous fish is more vulnerable to this anthropogenic impact. Furthermore, the concentration of plastic particles affects fish growth and body condition. (Critchell & Hoogenboom, 2018)
Sea birds	Tasman Sea (between Australia and New Zealand)	The threat of plastic ingestion to seabirds is globally widespread, pervasive, and increasing. The research showed that 59% of studied species had ingested plastics, with an average of 29% of individuals had plastics in their guts. Three factors, including debris ingestion rates of seabirds, increasing plastic exposure, and body size were positive correlated. In other words, ingestion rates are expected to increase proportionately, as more plastics are found in the ocean. The research predicted that 99% of all seabird species will be affected by plastic ingestion by 2050. (Wilcox et al., 2015)
Turtles	Japan	Sea turtles are suffering from a significant stress of artificial marine debris ingestion. Using animal-borne video cameras and analyses of feces and gut contents, the researchers found evidence of plastic ingestion in loggerhead turtles *Caretta caretta* and green turtles *Chelonia mydas*. These species of turtles confuse transparent drifting soft plastic debris with their diet,

	e.g., gelatinous prey due to the similar characteristics (colors, drifting in water column). Due to different feeding habits and vertical distribution of food in the water column, these species of turtles expose to different risks of plastic ingestion. (Fukuoka et al., 2016)
Atlantic Ocean, Mediterranean Sea, and Pacific Ocean.	The study reported the presence of synthetic particles as well as microplastics in all sampled individuals (100%) belonging to seven species of marine turtles. These animals were collected as being stranded or bycaught in three ocean basins in the Atlantic, Mediterranean, and Pacific, including green *Chelonia mydas*, loggerhead *Caretta caretta*, Kemp's ridley *Lepidochelys kempii*, leatherback *Dermochelys coriacea*, flatback *Natator depressus*, hawksbill *Eretmochelys imbricata*, and olive ridley turtles *Lepidochelys olivacea*. Among ingested synthetic materials, fibers are the most common type detected, followed by fragments and microbeads. The research also discussed multiple potential pathways of ingestion. For instance, as several marine turtles feed at benthic level, contaminated sea water or sediments could be the source of synthetic particles, which were ingested along with turtles' prey. Besides, forage items or contaminated prey, e.g., filter feeding invertebrates, may acts as vector of trophic transfer to marine turtles. Finally, the researchers raised the necessary of further research for potential impacts of plastic pollution and

	associated contaminants on marine turtles. (Duncan et al., 2019)
Atlantic Ocean, Indian Ocean, Mediterranean Sea, Pacific Ocean.	Earlier, other researchers conducted a comprehensive review of scholarly literature regarding the current knowledge of marine plastic debris and this anthropogenic pressure on marine turtles. The study focuses on seven species of marine turtles; namely, flatback *Natator depressus*, green *Chelonia mydas*, hawksbill *Eretmochelys imbricata*, Kemp's ridley *Lepidochelys kempii*, leatherback *Dermochelys coriacea*, loggerhead *Caretta caretta*, and olive ridley *Lepidochelys olivacea*. All of those species suffer from plastic ingestion and entanglement. Plastics are ingested by turtles via two potential pathways: direct consumption of plastics due to mistaken identity as prey, and accidental ingestion in case of mixture of plastics and normal prey. Damages from plastic ingestion include, *inter alia*, internal blockage and injury, an increase of buoyancy, and other lethal effects; whereas, entanglement in plastic debris (including ghost fishing gear, other nylon or plastic wastes from land-based sources) causes a reduction of foraging and escaping ability, as a result, these animals suffer from drowning, starvation, and fatal damages. Furthermore, at the population level, MPP presence at the nesting beaches may affect the temperature and characteristics of the sediment, and as a result alter the hatchling sex ratios due to their temperature-dependence; thus, lead to the wider ecosystem effects

		of productivity loss. The review also noted the potential accumulation chemical contaminants from the marine environment with microplastics acting as transferring vectors. In their conclusion, the researchers underscore the need of raising public awareness with regards to these matters concerned, together with enhancing cooperation among governments, industries, scientists, and other stakeholders. (Nelms et al., 2016)
Seaweed	Samples collected from North Sea, Germany; Laboratory experi-ments.	The research provided the first evidence that seaweeds act as a vector for microplastics transferring from water to marine benthic herbivores, then into marine and coastal food webs. In detail, suspended particles of microplastics, e.g., microbeads, fragments, and fibers, adhered to the surface of brown seaweeds. The amount of microplastics that adsorb on the algae surface correlated with the concentration of particles. Besides, different morphological features among algal species, e.g., surface depressions and hairs, accounted for different degree of contamination at similar particle concentrations. The brown algae contaminated with microplastics becomes available for herbivorous consumers. Periwinkles cannot distinguish between algae contaminated with adherent microplastics and clean algae without suspended particles. Thus, these meso-herbivores ingest microplastics through contaminated seaweeds. Consequently, microplastics are found in the stomach and gut of these species. (Gutow et al., 2016)

Bivalves	Samples collected from Cornwall, United Kingdom; Laboratory experi-ments.	As plastic debris accumulates and fragments in the environment, their smaller particles can be ingested by animals. For investigation of ingestion, translocation, and accumulation of microscopic plastic particles (< 1 mm), the mussel species *Mytilus edulis* were collected from a site in Cornwall (UK) and examined in laboratory conditions. This mussel species was chosen due to their geographic popularity and their important role in the base of the tropic levels to many intertidal-zone predators, including humans. The result of the study shows that microscopic plastic particles were ingested by those mussels; then, these particles were transported to the gut, and translocated from the gut cavity to the hemolymph (the circulatory fluid, analogous to blood) of the circulatory system within three days, and remained in the system for more than 48 days. The researchers, therefore, assumed that this long persistence period may cause the various tissues to be contaminated by chemical additives. (Browne et al., 2008)
Jellyfish	Mediterrane an Sea	The study is the first report showing the presence of macroplastics in jellyfish species *Pelagia noctiluca*. Night-diving observations of mauve stinger specimens were conducted in the Mediterranean Sea. There were 20 specimens of *P. noctiluca* collected. The studied site has complex hydrodynamic characteristics with prominent surface and upwelling streams, which concentrate drifting litters and planktonic species in the same geographic area. The research's findings

		highlight the impacts of plastic pollution on medusae. Usually, due to their density, drifting weathered litters float near the sea surface and having a similar behavior as neuston organisms. As a result, jellyfish species, especially *P. noctiluca*, actively ingests these fragments of marine litters, which are wrongly recognized as prey. The result shows that anthropogenic litters of different types, shapes, sizes, and colors were internalized by mauve stinger *P. noctiluca*. The organs where these materials were trapped and retained are oral lobes and hood. The field observations showed a strong connection between floating marine debris and jellyfish. In other words, jellyfish acts as vector of plastics along marine trophic webs. As pelagic top predators consume the mauve stinger as their key prey, impacts of plastic pollution on *P. noctiluca* might cause consequences on its predators, and further on marine wildlife and marine ecosystems. (Macali et al., 2018)
Amphipod	The Pacific Ocean; Six deep-ocean trenches: Izu-Bonin, Japan, Kermadec, Mariana, New	The research demonstrated the first record of plastic contamination and microplastic ingestion in "the very deepest reaches of the oceans". Totally, the surveys between 2008 and 2017 examined 90 sampled individuals of the lysianassoid amphipods species *Eurythenes gryllus*, *Hirondellea dubia*, and *Hirondellea gigas*, at nine hadal-zone sites, with depths ranging from 7,000 m to approximately 11,000 m. The results showed that microparticles of synthetic materials, plastics, semi-synthetic, and natural fiber

	Hebrides, Peru-Chile.	are found in the hindguts of 65 sampled individuals (approximately 72.22%). The study underscores those plastic materials found in the amphipods, including PA, PE, PVA, and PVC. Besides mentioning the depths of the surveyed sites, the research also highlights the distances between those deep-ocean trenches, ranging from over 8,000 km to over 15,000 km. These two ranges both of horizontal and vertical dimensions demonstrate the omnipresent nature of the anthropogenic debris. Critically, the researchers concluded with their rigid assumption of the probability of "no marine ecosystems left that are not impacted" by MPP. (Jamieson et al., 2019)
POLLUTED SITES		
Sea surfaces	Mediterranean Sea	The Mediterranean Sea has particular characteristics, in terms of geographic features and anthropogenic activities. In detail, the Sea is semi-enclosed, and located in basins with high anthropogenic activities and pressures; for instance, the area is located at the intersection of major international shipping routes, including the Strait of Gibraltar, the Suez Canal, and the Bosphorus Strait, with busy seaborne traffic (UNEP/MAP & Plan Bleu, 2020). The surveys were conducted in 28 sites across the Mediterranean basin, where floating plastic debris was sampled using net tows. The result shows that plastics were detected in all net tows (100%) carried out in these sites. Microplastics accounted for 83% of the total plastic

		items collected. The study identifies the Mediterranean Sea as "a region of particular high plastic concentration". The researchers also raised concern regarding impacts from plastic pollution and its associated toxicological effects on living organisms within the biodiversity-rich ecosystem of the Mediterranean Sea. Ultimately, the researchers addressed the need to target plastic prevention at pollution sources in management strategies in order to prevent plastics from entering the marine environment. (Cózar et al., 2015)
Coastal area	Korea	The spatial distribution of microplastics, especially in coastal areas, shows a correlation between the shore-based sources of pollution and marine plastic abundance. The studied sites were eight coastal waters in Korea, which were divided into two groups according to levels of anthropogenic activities; namely urban areas (in close proximity to large industrial facilities, e.g., metropolis, industrial complex, and sea ports), and rural areas (with less anthropogenic activities, mainly fishing and aquaculture). The result shows that urban areas had higher mean abundance of microplastics in comparison with rural areas. This indicates that large-scale anthropogenic activities contribute greater microplastic input into the marine environment. Besides, the researchers also noted that primary pathways for plastic waste from the land-based sources to enter open ocean are major rivers in the coastal cities. In terms of plastic types, EPS was

		the most abundant form among sampled microplastic particles, followed by paint particles, fragments, and fibers. (Kwon et al., 2020)
Beaches	Hong Kong	The studied area was 25 beaches selected among 500 sandy beaches at the Pearl River estuary. Beach surveys were conducted during the wet season with significant discharge from the river. The result shows that plastics were found in all samples collected from 25 beaches. In detail, microplastics accounted for the vast majority with over 90% of the total amount, in comparison with a minor proportion of macro-plastics. In terms of type, EPS was a dominant form representing over 90%, followed by fragments and pellets. The report shows that Hong Kong had the highest mean plastic abundance (in unit of items per m^2) found on beaches in comparison with similar studies, indicating that the area is a hotspot of microplastic pollution. The sources of plastic pollution are the densely populated urban areas and the large river estuary. The pathways of plastics are wind flows, storm water drainage systems, and significantly, the Pearl River. The researchers highlighted that the use of plastic bags, food packaging, and PS lunch boxes is a common practice in Hong Kong. Some factors, which influence the accumulation of plastics on beaches, include the direction of surface currents, the waste collection and management system, as well as the frequency of conventional beach maintenance. However, beach maintenance only targets large debris.

		The researchers, therefore, suggested the reduction or prevention of input or release of plastics at their sources as the most effective measure for reducing microplastic pollution. (Fok & Cheung, 2015)
Estuary	United Kingdom	The studied site was estuarine shorelines of the Tamar River. Various items of plastic debris were found from 30 samples of sediment. The majority of recorded debris was microplastics with 65% of the total amount. In terms of usage, packaging materials, fishing line, and ropes used on ships, were recorded, *inter alia*. Among types of polymers, PE and PP were more abundant in comparison with other types of plastics due to the different levels of production. The spatial patterns of plastic waste distribution are strongly influenced by wind, with greater quantities of plastics found at downwind sites. Density of the particles and the movement of water flow also affects the accumulation of plastic debris. Besides, the researchers also mentioned the discharges of sewage treatment plants as another source of microplastic debris to the estuary. (Browne et al., 2010)
	Indonesia	The sampling areas were along 500 meters of Madura Strait coastline at the estuary of Wonorejo River. The samples were collected twice a day with the purpose to analyze the correlation between the tidal effect, i.e., high tide and low tide, and the accumulation of plastic waste. The result shows that there was a significant difference between total weight of plastic debris

		collected during high tide and low tide. In detail, in all sampling locations the amount of collected debris was significantly higher during high-tide period of the Madura Strait. In terms of polymer types, there were different forms recorded, with LDPE being the most abundant type due to its floating characteristics, followed by PP and PS. The researchers noted that, although manual cleaning of large plastic debris remains the main mechanism to minimize plastic waste, prevention of plastics to enter the ocean is of importance in avoiding the fragmentation of larger plastic debris into smaller particles. In their conclusion, the researchers suggested local government to consider the tidal effect in plastic accumulation when conducting manual plastic cleaning processes; for instance, to perform coastline and estuary cleaning during high tide for more effective cleaning result. (Kurniawan & Imron, 2019)
HUMAN-CONSUMPTION-RELATED		
Table salt	China	Products from sea, including sea salts are among the main sources of food for humans. Microplastics have been found in sea water all over the world. Undoubtedly, sea products are also contaminated by microplastics. Through the food chain, microplastics can be transported to humans, increasing potential health risks for the top consumers. The researchers collected 15 brands of table salts in China, materials of which mainly come from the sea, saline lakes, saline

	rocks or wells, for identification of microplastic particles. The results show that particles of fibers, fragments, and pallets have been found in these samples of table salts. Sea salts have the largest number of particles, following by lake salts, and rock/well salts. Among brands of sea salts, there is no significant difference in the number of particles found. PET was found as the most common polymer in sea salts. These results suggest that water at the coastal and estuarine areas of China, which are the primary sources of sea salts, is contaminated by microplastics. According to the researchers' calculation, an adult may ingest approximately 1,000 particles annually from table salts. Microplastics with chemical additives and contaminants, and their presence in table salts may pose a threat to food safety. (Yang et al., 2015)
Spain	Similarly, 21 different brands of commercial table salts from Spain were analyzed for the presence of microplastics. The results show that microplastic particles were found in these marine salts' samples with no significant difference. Among polymer types, PET was the dominant type found in the samples, followed by PP and PE. The researchers highlighted the hazardous effect from the presence of microplastics in the sea water. Plastics might absorb contaminants, e.g., POPs, and transfer to sea products, which are consumed by humans at the top of the food chain. This might pose a threat to food safety. (Iñiguez et al., 2017)

	Australia, France, Japan, Malaysia, Portugal, South Africa	Likewise, 17 brands of commercial salts originating from 8 different countries were collected for identification of microplastics. The results show that microplastics were found in all brands except only one. The dominant form of microplastic particles is fragments, followed by filaments and films. Regarding polymer materials, PP and PE are the most common types found in tables salts. The researchers highlighted that the consuming sea products containing microplastic particles in the long term may become a concern. (Karami et al., 2017)
Edible seaweed	Samples collected from Denmark; Laboratory experiments.	Microplastics in the ocean raise concern regarding pollution of seafood, including edible seaweed. The research shows evidence of the adherence of PS microplastic particles to edible macroalga *Fucus vesiculosus*; thus, contributes to fill the knowledge gap regarding the mechanisms of the physical interactions between microplastic particles and seaweeds. Besides, although a significant reduction of PS particles was observed after washing in laboratory conditions, an average of 5.5% particles still remains on the algae surface. This result can be applied for optimal removal of microplastic particles in relevant seaweed cleaning and processing procedures at industrial scale prior to human consumption. The researchers emphasized the absence of studies on seaweeds as a route of the direct human exposures to microplastics. (Sundbæk et al., 2018)

Fish for human consump-tion	Japan	Approximately 80% of the sampled Japanese anchovy species *Engraulis japonicus* had microplastics in their digestive tracts. Most of the plastic materials found in these fishes were PE and PP, and they were fragmented. Likewise, microbeads, manufactured particles in personal care and cosmetic products, were found in these fishes' stomachs. The research confirms that marine ecosystems have been infiltrated by microplastics globally, and humans, through marine food web, are exposed to these anthropogenic impacts when consuming contaminated seafood, in this case, anchovies. As plastics contain various hazardous chemicals, the plastic ingestion of anchovies may increase chemical exposure to humans, as the top consumers in the food chain. Critically important, Japanese anchovy is a common food in Japan. (Tanaka & Takada, 2016)
	Remote South Pacific islands: Western and Eastern French Polynesia, Henderson Island, Lord Howe Island.	Plastic contamination in South Pacific fishes is reported for the first time through this research. Fishes of 24 species were sampled. Totally, there were 126 samples collected from the local fishers or at the local markets in remote locations of South Pacific, which were caught for human consumption. The result showed that plastic particles (mostly microplastics, e.g., rope, nurdles, and fragments) were found in gastrointestinal tracts of 10 individuals (approximately 8%), and 6 species (approximately 25%). The study demonstrates the wide range of plastic pollution and plastic ingestion in various fishes

of different feeding behaviors, different trophic levels (from herbivores to top predators), habitats (coastal, pelagic, and reefs), and life stages (larvae, juvenile, and adult). The researchers also underscored several severe effects of plastic ingestion to those species, including, *inter alia*, blockage, injury, contamination by harmful substances associated with plastic productions. Extremely important, those chemical pollutants, which may accumulate and contaminate those fishes through their tissue upon ingestion, can cause potential harmful effects to human health. These negative impacts are, especially, underscored in case of un-gutted small-size fishes, which are consumed in in local islands, besides their gutted larger-size counterparts. Equally important, 30% of the total plastic particles detected inside those fishes were nurdles or plastic feedstock pellets. Due to the absence of plastic factories in the vicinity of the study sites, the researchers concluded that those pellets come from other locations, either being transported through wind and current from distant industrial centers, or being lost at sea from vessels. All in all, these evidences, which are studied in the remote locations in the Pacific Ocean, emphasize the omnipresent nature of plastic contamination in general, and the ingestion of plastics by commercial fish species in particular; thus, raising concerns regarding the chemical effects when entering the food chain, going upwards the trophic levels, and finally, to humans. (Forrest & Hindell, 2018)

Commercial-ly grown bivalves	North Sea, Atlantic Ocean	Microplastics are found in commercially grown bivalves: the mussel *Mytilus edulis* and the oyster *Crassostrea gigas*. The mussel was reared in the North Sea; whereas the oyster was cultured in the Atlantic Ocean. These commercially grown species feed on natural algae in the seawater. Bivalves, due to their extensive filter-feeding activity, are directly exposed to any pollutant in the seawater, including microplastics. Due to their persistent characteristics, the accumulation of microplastics in the marine environment will only increase. The current increasing scientific evidence of microplastic ingestion of numerous marine species show that these particles are entering the marine food chain; thus, causing a threat to food safety for humans. In fact, when consuming a portion of mussels or oysters, one person may consume approximately 50-90 particles of microplastics. (Van Cauwenberghe & Janssen, 2014)
Human stools	Austria, Finland, Japan, Italy, Nether-lands, Poland, Russia, and United Kingdom	The first study of its kind detects the presence of plastic particles in human stools. In detail, a group of participants from countries across the globe provided stool samples in a world-wide pilot study. With consideration regarding usage of toothpaste and cosmetic products, chewing gum, alcohol intake, vegetarian diet, and contact to plastic-wrapped food, and especially drinking habits from PET bottles and seafood consumption, the stool analysis showed that all samples (100%) were exposed to plastic particles and fibers. With these analysis results, the researchers

estimated that microplastic particles might be found in the stool of over 50% of the world's population. The results found nine different plastic types in stool samples, sized ranging from 50 to 500 μm, with PP and PET being dominant types. Dr. Philipp Schwabl commented that this very first study confirms that "plastics ultimately reach the human gut". The lead researcher also raised the particular concern of microplastic impacts on human health, especially to patients who are suffering from gastrointestinal diseases. Furthermore, the capability of the smallest microplastic particles to enter the blood stream, lymphatic system, or the liver is required for further study. (Schwabl et al., 2018; United European Gastroenterology, 2018)

Appendix B

MARINE PLASTIC POLLUTION: KNOWLEDGE GAPS

Table S2

Marine plastic pollution: Knowledge gaps

Category	Knowledge gaps ▶ Recommendation (if any)
FUNDAMENTAL AND GENERAL KNOWLEDGE	
	There is a lack of knowledge regarding sources (including quantitative contributions for each stage from production, consumption, to post-consumption; especially, the quantity from land-based sources), pathways of plastics in the marine environment, and the causes of harmful effects. Besides, quantitative impacts of marine plastics on the biodiversity-rich habitats of coral reefs, and the subsequent harmful effects on the fisheries biodiversity and productivity are currently unclear. ▶ More research is needed to facilitate the formulation and implementation of effective solutions and interventions. In addition, studies are required for the definition of "hazardous wastes" and its subsequent qualification of plastic types and products, accordingly. (Almroth & Eggert, 2019; Mendenhall, 2018; Jambeck et al., 2015)
	Some aspects of the co-occurrence of climate change and plastic pollution, as well as their present and future

	impacts are still insufficiently explored. Besides, although detrimental effects of MPP to coral reefs have been studied by some researchers, it is currently unclear about the additional extent of MPP exacerbating impacts on occurring threats from climate change to those biodiversity-rich habitats. Furthermore, the fragmentation processes of microplastics into even smaller fragments (e.g., nano-particles) are also incompletely understood. (Ford et al., 2022)
HUMAN-HEALTH-RELATED	
	The current limited number of studies can only support to estimate "a preliminary dietary exposure" of microplastics to humans via seafood consumption. Some studies are limited to specific areas and marine species. This insufficiency of dedicated and effect studies hinders the understanding and comprehensive assessment of the hazards to human health posed by microplastic-contaminated seafood. (Van Cauwenberghe & Janssen, 2014; Mendenhall, 2018)
	Although the findings of plastic ingestion in many fish species in the remote South Pacific islands raise particular concerns, especially to human health, the current understanding regarding MPP in the region is rather scarce. ▶ The researchers underscore the need for further studies on the issues of MPP at a global scale, and particularly, specific marine species impacted by plastic ingestion;

	thus, facilitating actions and implementation of national strategies and policies. (Forrest & Hindell, 2018)
	Concerns of microplastic contamination in sea vegetables are increasingly raised. However, there is still an absence of studies on the direct human exposure to these micro-sized particles via contaminated seaweed. ▶ Expansion of understanding regarding seaweed as means of microplastic exposure to humans is of particular necessity, both for farmed and naturally harvested algae. (Sundbæk et al., 2018)
	The role of seaweed as a transferring vector is currently unclear. ▶ Further research on microplastic quantity and distribution in the marine environment, taking into consideration their habitat sites and associated consumers. (Gutow et al., 2016)
	Studies on the plastic-human interactions and their adverse impacts on human health are scarce. (Almroth & Eggert, 2019; Schmaltz et al., 2020)
MARINE-LIFE-RELATED	
	Considering that the researches on MPP are relatively new, a vast majority of the ocean is still unexplored, including even the hotspot of plastic accumulation zone in the Mediterranean Sea. ▶ Special attention regarding the toxicological impacts on marine organisms is needed in case of the biodiversity-

	rich ecosystem in the Mediterranean Sea. (Cózar et al., 2015)
	Plastic ingestion and its effect of bioavailability culmination are recorded in the deepest reaches of hadal zones, of which the species and the environment are currently insufficiently understood. Besides, the mechanisms of digestion and defecation of microplastics, the extent of microplastic dispersion across the seafloor, and the effect of marine litter interaction of these deep-sea species are currently unknown, due to the impossibility of experimental observation and prior-contamination data collection. (Jamieson et al., 2019; Mendenhall, 2018)
	The impacts of microplastics on marine wildlife are insufficiently understood. In addition, the translocation mechanism from the gut cavity to the circular system of invertebrates, as well as the different effects between smaller particles versus larger particles of microplastics are currently unclear. ▶ Further studies are required to understand these translocation and accumulation mechanisms in these invertebrates. Besides, research on longer-term toxicological effects from various plastic types to marine habitats, and the potential damages to vital organs of these species, as well as the methodology and technique for quantitative assessment of small plastic fragments are needed. (Browne et al., 2008)

Knowledge on microplastic ingestion in marine turtles is limited. The impacts of microplastics on these marine species remain unknown. ▶ Further research is needed to examine the ingestion pathways of microplastics, as well as the specific species and their particular impacts. (Duncan et al., 2019)
There is a lack of publication of plastic and marine debris ingestion in marine mammals in the South East Pacific. ▶ The researchers call for urgent implementation of scientific action plans for treatment of stranded marine mammals in order to increase the knowledge on marine litter ingestion in these species. In addition, assessment of hotspots of MPP is also needed for resources allocation and conservation measures. (Thiel et al., 2018)
Scientific evidence of plastic ingestion and its impacts on individual and population levels of seabird species are still relatively scant. (Wilcox et al., 2015)

Appendix C

MARINE PLASTIC POLLUTION: CHALLENGES

Table S3

Marine plastic pollution: Challenges

Category	Challenges
CHARACTERISTIC RELATED	Due to the small size of microplastic particles, it is impossible to trace back to their sources of origin, and remove these fragments from the open environment (Almroth & Eggert, 2019; Jambeck et al., 2015).
	The nature of the issue of MPP itself also causes difficulties; for instance, mostly out of sight, difficult to assess, quantify, and identify sources, harmful in transboundary movements, mostly beyond national jurisdiction. (Almroth & Eggert, 2019; Mendenhall, 2018)
RESEARCH RELATED	The inconsistency within the body of knowledge also creates difficulties for further researches and studies. In detail, definitions, terminologies, and size ranges vary among different researchers and institutions (Browne et al., 2008; Duncan et al., 2019; Ferraro & Failler, 2020; Fok & Cheung, 2015; Forrest & Hindell, 2018; Mendenhall, 2018; Nelms et al., 2016; Van Cauwenberghe & Janssen, 2014; Wysocki & Billon, 2019).
	Many areas are remote in locations and harsh in conditions also create difficulties and challenges in approaching and proceeding research. (Mendenhall, 2018)
MANAGEMENT AND GOVERNANCE RELATED	Regarding plastic recycling, technical challenges come from the complexity of input materials, the mixtures of various plastic types, and the lack of transparency of chemical composition used during manufacturing processes (Almroth & Eggert, 2019; Wysocki & Billon, 2019).

The current limited number of policies in tackling plastic pollution is in contrast with the enormous scale of this global issue. Besides, the significant knowledge gaps and their relevant uncertainty also affect the development and establishment of effective measures and policies. (Kurniawan et al., 2021; Mendenhall, 2018)
Waste management also faces challenges from plastic pollution due to the persistency and durability of plastic materials, which leads to long naturally degradation period; thus, almost all ever produced plastics still exists. Furthermore, despite the on-going efforts in clean-up activities, most of plastic materials ever created has not yet been collected. The limited capacity of the current waste management and recycling infrastructure, therefore, is overloaded by the enormous past input, as well as the current accumulation of plastic pollution. (Forrest & Hindell, 2018; Hwang, 2020; Mendenhall, 2018; UNEP, 2019c)
The omnipresent nature and enormous extent of plastic pollution requires concerted efforts and collaborative contributions across all stakeholders in a large responsive (in tandem with preventive) scale at global level. (Schmaltz et al., 2020; Wysocki & Billon, 2019)

Appendix D
SUPPLEMENT MATERIALS
THE RELEVANT INSTRUMENTS: BRIEF REVIEWS

Within the scope of the Dissertation, several international instruments, documents, and strategies are reviewed and briefly described. In general, these reviews reflect the interpretations and understandings of the Author from the perspectives of the Author, when studying and researching these materials, which are retrieved from respective institutions (See Chapter 2). Therefore, the primary sources of these relevant and mentioned instruments, documents, and strategies shall be referred to.

1. The United Nations Convention on the Law of the Sea (UNCLOS)

The United Nations Convention on the Law of the Sea (UNCLOS) is a legal framework for the seas and the oceans, all issues relating to the law of the sea, and all activities carried out therein, for the purposes of "maintenance of peace, justice and progress for all peoples of the world" in general, and for the protection and preservation of the marine environment in particular (UN, 1982). In terms of the marine environment and related aspects, UNCLOS establishes legally binding obligations upon the States Parties for not only ship-based and sea-based sources of pollution, but also for the prevention, reduction, and control of pollution of the marine environment from land-based sources. In detail, Part XII of UNCLOS establishes regulations regarding the protection and preservation of the marine environment, of which the first six sections are briefly reviewed, including general provisions (Section 1), cooperation and technical assistance (Section 2 and Section 3), monitoring and assessment (Section 4), international rules and national legislation (Section 5), and ultimately, enforcement (Section 6).

In the first place, general provisions of UNCLOS Part XII are discussed. Parallel to their sovereign right to exploit their respective natural resources, States have their

duties and obligations to protect and preserve the marine environment (Articles 192 and 193). Article 194 requires States to take appropriate and necessary measures, which are consistent with the Convention and in harmony with their national legislation, to prevent, reduce, and control pollution of the marine environment from all sources, including, *inter alia*, from land-based sources, by dumping, air pollution, ship-based sources, exploration- and exploitation-related activities, and offshore installations and devices. Besides, while taking those mentioned measures, States are required to ensure no damages caused by pollution, and no spreading beyond their sovereign areas and affecting other States and their respective environment. In detail, Article 195 requires States not to transfer or transform damages or hazards caused by pollution into another in terms of locations and types. In particular, regarding the requirements for those mentioned measures, Articles 194(5) takes into consideration the protection and preservation of fragile and rare ecosystems, and habitats of endangered, threatened, or depleted species, as well as other forms of marine life. Regarding the intentional or accidental introduction of alien or new species, Article 196 requires that all necessary measures shall be applied for the prevention, reduction, and control of marine pollution, which results from such introduction with significant and harmful impacts on the marine environment.

Section 2 and Section 3 of this Part establishes provisions regarding international and regional cooperation, as well as technical assistance. For instance, UNCLOS requires States to cooperate at global and regional levels, possibly through the competent international organizations, e.g., the International Maritime Organization (IMO), in formulating and elaborating recommended practices and procedures, standards, and international rules, which are in consistent with the Convention, for the purposes of the protection and preservation of the marine environment, with particular consideration for regional features and characteristics (Article 197). These formulation and elaboration of recommended practices and procedures, standards, and international rules shall be based on appropriate scientific criteria for regulations (Article 201), which are acquired from exchanged information and data via promoted studies, regional and global programmes of scientific research regarding marine

pollution in general, and the assessment of the nature, extent and exposure of pollution, its pathways, and risks, as well as countermeasures for marine pollution in particular (Article 200). In addition, in case of imminent or actual damage to the marine environment (Article 198), the acknowledged State shall without delay notify other States, which might be affected by such damage, as well as inform the competent international organizations, e.g., the IMO.

Equally important, contingency plans for pollution incident response shall be jointly developed and promoted by the acknowledged State and affected States in that area for the purposes of damage prevention and minimization, and pollution elimination (Article 199). As a matter of fact, developing States need appropriate assistance for the protection and preservation of the marine environment, as well as the prevention, reduction, and control of marine pollution. Recognizing this matter, UNCLOS establishes provisions to provide assistance and support to developing countries (Articles 202 and 203). In detail, States are required to provide technical, scientific, and educational assistance (e.g., training of personnel, participation in international programmes, provision of equipment and facilities, enhancement of manufacturing such equipment, consultation, appropriate assistance for responding major incidents and minimizing their negative effects, as well as for environmental assessments), to developing States either directly, or via the competent international organizations, e.g., the IMO. Furthermore, in allocation of funds and technical assistance, as well as the utilization of specialized services, preferential treatment shall be provided to developing States by international organizations.

Section 4 of this Part establishes provisions regarding monitoring the risks or effects of pollution and the environmental assessments. In detail, States are required to monitor, i.e., to observe, measure, evaluate, and analyze, utilizing recognized scientific approaches, the risks and effects of marine pollution, as well as any permitted activities, which may have potential effects on the marine environment (Article 204). Similarly important, any planned activities, which may cause substantial pollution of or harmful and significant damages to the marine environment, shall be assessed by States through environmental assessments (Article 206). Consequently, reports on the

results of the monitoring and surveillance activities, as well as the environmental assessments shall be published, and submitted to the competent international organizations, e.g., the IMO, and made available to all States (Article 205).

Following these, Section 5 and Section 6 establish provisions concerning the international rules and national legislation in the prevention, reduction, and control of marine pollution, as well as measures for enforcement by flag States, port States, and coastal States. It is important to mention that in Section 5 and Section 6, provisions are oriented by sources of pollution, i.e., land-based, sea-based (including sea-bed activities and activities in the Area), by dumpling, and ship-based, as well as air pollution from or through the atmosphere. Table S4 demonstrates the relevance of provisions in Section 5 and Section 6 in terms of source-based division, and their internal link within UNCLOS, as well as external reference to other instruments (if any).

Table S4

UNCLOS Part XII, Section 5 and Section 6: Provisions regarding international rules, national legislation, and enforcement measures

Sources	**Provisions regarding international rules and national legislation**	**Provisions regarding enforcement**	**Internal link, External reference**
Land-based	Article 207	Article 213	
Sea-based: Seabed activities	Article 208	Article 214	UNCLOS, Part V: Article 60. Artificial islands, installations and structures in the

			exclusive economic zone. UNCLOS, Part VI: Article 80. Artificial islands, installations and structures on the continental shelf.
Activities in the Area	Article 209	Article 215	UNCLOS, Part XI: Section 2. Principles governing the Area, Article 136. Common heritage of mankind; Article 145. Protection of the marine environment.
By dumping	Article 210	Article 216	
Ship-based	Article 211	Articles 217, 218, 219, 220, 221	Routeing systems; SOLAS, Chapter V – Safety of navigation.
Air pollution	Article 212	Article 222	

First of all, regarding pollution from **land-based sources**, Article 207 requires States to adopt laws and regulations, as well as necessary measures, which are in harmony at the regional level, for the prevention, reduction, and control of marine

pollution from their respective land-based sources, e.g., pipelines, outfall structures, rivers, and estuaries, taking into consideration international rules, standards, and practices. Besides, at global and regional levels, rules, standards, recommended practices and procedures for the prevention, reduction, and control of marine pollution from land-based sources shall be established through competent international organizations or diplomatic conference, with particular consideration on specific regional features and characteristics, capacity and need of developing States. Also, the Convention requires that these established instruments are re-examined frequently as deemed necessary. Particularly important, Article 207(5) requires that these mentioned instruments shall be designed for the fullest extent of minimization (as possible) of the release of toxic, harmful and noxious substances, and especially persistent substances, into the marine environment.

Following the adoption of their laws and regulations according to Article 207 within their respective national legislations, States are required to enforce those instruments. Besides, applicable international rules and standards, which are adopted via competent international organizations or diplomatic conference for the prevention, reduction, and control of marine pollution from land-based sources, shall be implemented through necessary measures within their States' respective national legislations (Article 213).

Regarding pollution from **sea-based sources**, the UNCLOS provisions distinguish activities from seabed subject to national jurisdiction (Article 208) and from the Area (Article 209). In detail, similar to the above-mentioned provisions regarding pollution from land-based sources in terms of structure and requirements, Article 208 requires coastal States to adopt laws and regulations, as well as necessary measures, which are in harmony at the regional level, for the prevention, reduction, and control of marine pollution from their respective seabed activities, and from artificial islands, installations, and structures, which are subject to and under their national jurisdiction and in accordance with Article 60 and Article 80, i.e., concerning artificial islands, installations, and structures in the exclusive economic zone and on the continental shelf, respectively. It is of significant importance to highlight that,

Article 208(3) requires States to ensure that the effectiveness of these established laws, regulations, and measures is at least equal to or greater than international rules, standards, recommended practices and procedures, which are adopted collectively by States through competent international organizations or diplomatic conference, for the purposes of the prevention, reduction, and control of marine pollution from respective seabed activities, artificial islands, installations, and structures as described in Article 208(1). Also, similar instruments shall be established at regional levels by States. These mentioned global and regional instruments are required to be re-examined from time to time as deemed necessary.

Likewise, following the adoption of their national laws and regulations according to Article 208, States are required to enforce those instruments (Article 214). Simultaneously, through necessary measures within their respective national legislations, States shall implement applicable international rules and standards, which are adopted via competent international organizations or diplomatic conference, with the purposes to prevent, reduce, and control marine pollution from their respective seabed activities, as well as from artificial islands, installations, and structures, which are subject to and under their national jurisdiction as described in Article 208(1).

Regarding activities in the Area, Article 209 requires States to adopt international rules, regulations, and procedures pursuant to UNCLOS Part XI for the purposes of the prevention, reduction, and control of marine pollution arising from or in connection with activities carried out in the Area. Especially important, UNCLOS Article 136 affirms that the Area itself and all resources therein are "the common heritage of mankind". Therefore, pursuant to the Convention, Article 145 requires necessary measures are to be taken to ensure that the marine environment is effectively protected from harmful effects, which may arise from or be in connection with any activities carried out in the Area. For these purposes, appropriate rules, regulations, and procedures are to be adopted in order to, *inter alia*, prevent, reduce, and control of pollution and other hazards to the marine environment, the coastal areas, without any interference with the ecological balance of the marine environment, as well as to protect and conserve the natural resources in the Area, and to prevent any damages to

the flora and fauna in the marine environment (Article 145). Those mentioned activities include, but not limited to, waste disposal, drilling, dredging, excavation, and construction, operation, and maintenance of pipelines, installations, other devices and equipment related to those activities. Regarding the above-mentioned international rules, regulations, and procedures pursuant to Article 209, these instruments are required to be re-examined at a frequent interval as deemed necessary. In addition, national laws and regulations for the prevention, reduction, and control of marine pollution from activities in the Area, which are carried out by vessels, structures, installations, other devices and equipment under their States' respective flag or registry or authority, shall be adopted. The Convention, as described in Article 209(2), requires the effectiveness of these national laws and regulations to be either equal to or greater than those above-mentioned international instruments.

Particularly, the enforcement requirements in connection with pollution from activities in the Area (Article 215) are in accordance with UNCLOS Part XI – The Area. Generally, enforcement measures of international instruments for the purposes of the prevention, reduction, and control of marine pollution from activities carried out in the Area are required to be governed by the above-mentioned Part.

With regard to **pollution by dumping**, UNCLOS Article 210 requires States to establish their national laws and regulations, and to take other necessary measures with the purposes to prevent, reduce, and control such pollution to the marine environment. The Convention highlights the importance of States' competent authorities to ensure that only permitted dumping is carried out. Strictly promulgating, only if the coastal States express their prior approval for dumping within their territorial sea, their exclusive economic zone, or onto their continental shelf, with appropriate and due consideration with other States, which may be adversely affected by such dumping due to their geographical features and characteristics, then those activities could be carried out. The coastal States have the right for permission, regulation, and control of such dumping activities. In addition, States shall collectively adopt international and regional rules, standards, recommended practices and procedures, which are required to be re-examined frequently as deemed necessary, for the prevention, reduction, and

control of such pollution from dumping activities. Likewise, as previously discussed, the above-mentioned national laws, regulations, and measures shall be either equally or more effective than their international counterparts.

Concerning enforcement measures, not only the coastal States, who permit, regulate, and control dumping within their territorial sea, their exclusive economic zone, or onto their continental shelf; but also, the flag States, who shall ensure compliance by vessels registered under their flag or registry, as well as aircrafts of their registry, and any other States involve in activities in connection with loading of wastes or other matter at their off-shore facilities or within their territories (Article 216). Besides, there is a provision with regard to the institution of proceeding in accordance with this Article.

Critically, UNCLOS highlights the particular importance of the prevention, reduction, and control of pollution to the marine environment from ship-based sources or vessels through a range of provisions, including, *inter alia*, Article 211 for the international rules and national legislation, as well as Articles 217–221 for the enforcement measures. Provisions with regard to air pollution are also discussed at the later stage. In the first place, international rules and standards for the prevention, reduction, and control of pollution to the marine environment from vessels shall be adopted collectively by States via the competent international organization, i.e., the IMO, according to Article 211. Similarly important, "routeing systems" are to be promoted for adoption as deemed appropriate. These systems, one function of which, *inter alia*, is to reduce or minimize the risk of maritime casualties, accidents and incidents, and therefore, contribute to maritime safety and the protection of the marine environment not only to the nearest coastline, but also, to other related interests of the coastal States (IMO, 1974). It is necessary to discuss about the interconnected relations and contributions between maritime safety and security (as in connection with the SOLAS Convention) and the protection of the marine environment; especially, for instance, in case of containers lost at sea, including lost cargo of plastic materials and plastic pellets, as results of maritime casualties.

These mentioned rules and standards, including those promulgating “routeing systems”, are to be re-examined at frequent interval as deemed necessary. Explicitly, in case of incidents in general or maritime casualties in particular, in which discharges or risks of discharges may arise or be involved, the coastal States may be affected, especially to their coastline and related interests. UNCLOS, therefore, pursuant to Article 211(7), requires specific provisions regarding “prompt notification” to coastal States to be included into the above-mentioned international instruments.

Besides those international instruments, States are required to establish their national laws and regulations for the same purposes of the prevention, reduction, and control of pollution of the marine environment arising from or in connection with their vessels under their flag or registry. Likewise, these national instruments shall have their effectiveness at equal to greater level in comparison with their international counterparts. For the same purposes with regard to the marine environment, when particular port entry requirements are established for foreign vessels to enter their ports, internal waters, or offshore terminals, States shall duly publish and communicate those requirements to the competent international organization, i.e., the IMO. In this regard, policy harmonization via cooperative arrangements can be established at the regional level between two or more coastal States. All in all, UNCLOS Article 211(3) highlights that the right of innocent passage of vessels (pursuant to Part III. Straits used for international navigation, Section 3. Innocent passage, Article 45. Innocent passage) and the rights of protection of the coastal State for the prevention of any violation of entry conditions (pursuant to Part II. Territorial Sea and Contiguous Zone, Section 3. Innocent passage in the Territorial Sea, Subsection A. Rules applicable to all ships, Article 25. Rights of protection of the coastal State, Paragraph 2) are not prejudiced by this Article. With regard to the territorial sea of coastal States, for the purposes of exercising their sovereignty, national laws and regulations may be established to prevent, reduce, and control marine pollution from foreign vessels, including those vessels exercising their right of innocent passage. Furthermore, with regard to the exclusive economic zones of coastal States, for the purposes of enforcement (pursuant to Section 6 of this Part), national instruments may be adopted

in accordance with generally accepted international rules and standards, which are established via the competent international organization, i.e., the IMO, or general diplomatic conference. In accordance with Article 211(6), special mandatory measures for the prevention of marine pollution from vessels in a "particular, clearly defined area" with special circumstances within their respective exclusive economic zones of coastal States, taking into account the current ecological and oceanographical conditions, the protection and the utilization of resources therein, as well as the features of maritime traffic, may be communicated to the competent international organization, i.e., the IMO, for consideration. The procedures include appropriate consultations with other concerned States and the Organization itself; followed by a direct communication to the Organization with a submission of supporting technical and scientific evidence, as well as information regarding necessary reception facilities. Following the Organization's determination of the correspondence between the factual conditions and the communicated requirements, the coastal States' national laws and regulations for that particular area may be adopted in accordance with international instruments or navigational practices implemented for special areas via the Organization. Additional laws and regulations within the coastal States' national legislation, which may be established for those above-mentioned areas for the similar purposes, are required to have the scope limit to discharges or navigational practices, and not relate to standards of design, construction, equipment, or manning.

Regarding the enforcement measures with respect to pollution from vessels, there are several provisions applied not only to flag States, under whose flag or registry those vessels are registered, but also, to port States, coastal States, and the cooperation between those States for the purposes of enforcing the above-mentioned international and national instruments to prevent, reduce, and control pollution of the marine environment arising from or in connection with vessels (Articles 217–221).

In detail, UNCLOS Article 217 requires States to ensure that their vessels, which are registered under their respective flag or registry, to comply with applicable international and national instruments (as mentioned previously and pursuant to Section 5 of this Part); as well as to accordingly establish laws, regulations, and other

necessary measures for their national implementation with the purposes of the prevention, reduction, and control of marine pollution from vessels. In this regard, effective enforcement of such instruments shall be provided by flag States, regardless of the place of violation. Besides, prohibition from sailing is to be imposed on vessels through appropriate measures by States, under whose flag and registry those vessels are registered. The permission for proceeding to sea applied to those vessels only until they fully comply with the requirements of the above-mentioned international instruments. These provisions shall include, *inter alia*, requirements with regard to ship design, construction, manning and equipment of vessels. Furthermore, UNCLOS also highlights the particular importance of certification, certificates of compliance, their requirements and issuance in this respect. In detail, Article 217(3) stipulates that, appropriate certificates, which are required by and issued under international instruments pursuant to Paragraph 1 of this Article, are carried and available on board of their vessels, which are registered under their respective flag or registry. Also, periodic inspections shall be conducted by flag States for the verification of the conformity between the particulars of the certificates and the actual conditions on board those vessels. Regarding this aspect, further discussion can be conducted with respect to the "ultimate effectiveness" of implementation and enforcement of flag States in accordance with the IMO Instruments Implementation Code (III Code), and of their delegation of authority in accordance with the IMO's Code for Recognized Organizations (RO Code), as well as other related obligations and responsibilities (IMO, 2013b; IMO, 2013d).

With respect to certification, all issued certificates have the same and equal force, and shall be recognized and accepted by other States without any discrimination. However, in case of "clear grounds", i.e., evidence of substantial disagreement between the actual conditions of the vessel with the certificates' particulars, further enforcement measures are to be carried out (IMO, 2021a).

When a violation of international instruments is committed by a vessel, an immediate investigation shall be provided by flag States. With this regard, the provisions of Articles 218, 220, and 228 (concerning enforcement measures by port

States, coastal States, and the suspension and restrictions on institution of proceedings, respectively) are not prejudiced. Following the mentioned investigation, proceeding as deemed appropriate for the alleged violation shall be instituted regardless of the place of violation or pollution, either occurring or being spotted. Appropriate requests for assistance or cooperation upon conducting an investigation of the violation may be communicated by flag States to other States. Critically important, alleged violation committed by vessels registered under their flag shall be investigated by flag States, following the written request from any State; similarly, proceedings shall be instituted in accordance with their national legislation as deemed appropriate. UNCLOS requires that the severity of penalties pursuant to national instruments of States shall be adequate to discourage violations irrespective to the place of violation. Following the proceedings, the action taken and its results shall be promptly informed to the requesting State and the competent international organization, i.e., the IMO; and be made available to all States.

Upon arrival of a vessel at a port or an offshore terminal, an investigation may be undertaken by the port State. Besides, in case of a warranted evidence, proceedings for any discharge violation from that vessel, which is against those mentioned applicable international instruments and outside that port State's internal waters, territorial sea, or exclusive economic zone, may be instituted (Article 218). Those proceedings shall not be instituted for the waters under legislation of another State; unless either that particular State, the flag State of the vessel, or an affected State so requests; or unless the waters under the legislation of a State, who institutes the proceedings, have suffered from pollution or risks of pollution from that violation. In like manner, upon arrival of a vessel at a port or an offshore terminal, a request from either any State (hereinafter referred to as the requesting State, whose waters under their legislation have suffered from pollution damage arising from or in connection with a discharge violation), or the flag State regardless of the place of violation, for investigation on a discharge violation, shall be complied with by the port State. Following request from the flag State or the coastal State, the port State shall transmit the records of the conducted investigation to those States. Particularly, pursuant to

Section 7 of this Part regarding safeguards, the coastal State, whose waters under their legislation are the place of violation occurrence, may request to suspend any proceedings following such mentioned investigation, which are instituted by the port State. Afterwards, the port State shall transmit the case evidence and reports, and any financial security and bond posted with their authorities to the coastal State. Eventually, the proceedings' continuation in the port State shall be precluded upon such transmission.

Similar to the above-mentioned reference for further discussion with regard to the SOLAS Convention in particular, UNCLOS again highlights the ultimate importance of vessels' seaworthiness with regard to pollution avoidance through Article 219. In detail, when there are "clear grounds" ascertaining that a vessel's conditions are not seaworthy, and thereby cause risks or threaten damage to the marine environment, administrative measures shall be taken and the vessel shall be prevented from sailing by the port State. The only possible permission for the vessel is to proceed to an appropriate yard at the nearest distance for repair. Eventually, the sailing permit for the vessel shall be issued only after the violation causes are removed; in other words, the vessel is seaworthy and its condition and seaworthiness are in compliance with the mentioned applicable international instruments. These measures in respect of vessels' seaworthiness for pollution avoidance can be taken upon request or from own initiative of the port State pursuant to Section 7 of this Part concerning safeguards.

According to Article 220 regarding the enforcement measures by coastal States, when a vessel, within the coastal State's territorial sea or the exclusive economic zone, has violated their national laws and regulations, which are established pursuant to this Convention or applicable international instruments for the prevention, reduction, and control of marine pollution from vessels, and that vessel is in their port or offshore terminal, proceedings for that violation may be instituted by the coastal State pursuant to Section 7 of this Part. Besides, when a violation, which is against those mentioned national laws and regulations of a coastal State, occurred (with clear grounds of evidence) during a vessel's passage in the territorial sea of that State, a physical inspection of that vessel may be undertaken when it is navigating in their territorial

sea. Following the inspection, proceedings may be instituted, and there may be a detention of the vessel if there is warranted evidence pursuant to their national legislation and Section 7 of this Part. With regard to this provision, the relevant provisions of Part II, Section 3 concerning the innocent passage in the territorial sea, are not prejudiced. Furthermore, Paragraph 3 of this Article stipulates requirements regarding the provision of information from vessels. In detail, when a vessel, in the exclusive economic zone of a coastal State, has committed a violation, which is against the provisions of international instruments and their national legislation, and that vessel continues to navigate in their exclusive economic zone or their territorial sea, that vessel may be required by that State to provide information, including, *inter alia*, the vessel's identity, its port of registry, the last and the next port of call, and other relevant information. Following these requests, the violation occurrence can be determined. With this regard, national instruments shall be established by flag States to ensure that their vessels, which are registered under their flag or registry, observe the above-mentioned requests from the coastal State. In case of more serious and further escalation of the situation, for instance, there is significant marine pollution caused or threatened by a substantial discharge, and either there has been a refusion from that vessel to comply with the requests of information from the coastal State, or there is an obvious difference between the provided information from the vessel and the factual evidence of the situation, a physical inspection of the vessel for the violation matters may be carried out by that State, provided that such inspection is justified by the circumstances of that particular case. Equally important, when there is a major damage or risk of major damage to the coastal areas, related interests, or any resources within the territorial sea and the exclusive economic zone of the coastal State, which are caused by a violation discharge from a vessel navigating in their exclusive economic zone or their territorial sea, and only if there is warranted evidence, proceedings may be instituted by that State pursuant to Section 7 of this Part and their national legislation. The next provision of Paragraph 7 of this Article stipulates the obligation of the coastal State following appropriate financial security. In detail, when the coastal State is bound by either appropriate procedures adopted by the competent

international organization, i.e., the IMO, or mutual agreement, and when appropriate financial security or bonding is assured, the violated vessel shall be permitted to proceed to sea. The last paragraph of this Article demonstrates an internal link, in which Paragraphs 3 to 7 of this Article are to be implemented in national legislation in accordance with Article 211, Paragraph 6 with regard to a "particular, clearly defined area".

Critically vital, UNCLOS also highlights the damage, threat, and possibly major harmful consequences from maritime casualties to the marine environment, as well as measures to tackle pollution arising or in connection with such incidents or accidents (Article 221). In detail, following a maritime casualty, for the purpose of protection of their coastal areas, related interests, and fishing activities, enforcement measures can be taken beyond the territorial sea commensurate with the damage from the pollution or its threat. This right of States as mentioned shall not be prejudiced in accordance with conventional and customary international law. UNCLOS also clearly defines the term of "maritime casualty", including stranding, collision, navigational incident, or other occurrence happened on board or external to a vessel, which causes material damage or threat of such damage to a vessel or its cargo.

Finally in this Part, there are provisions regarding air pollution from or through the atmosphere (Article 212 and Article 222). In detail, according to Article 212, for the purposes of the prevention, reduction, and control of marine pollution from or through the atmosphere, States' respective sovereign air space and their vessels registered under their flag or registry, are subject to compliance to their national laws and regulations, as well as other necessary measures, which shall be established taking into consideration international instruments, and especially, the safety of air navigation. Similarly at international level, for the mentioned ultimate purposes, global and regional instruments shall be adopted collectively by States via competent international organizations, e.g., the IMO, or diplomatic conference. The final article of this Part stipulates the enforcement measures to tackle such air pollution (Article 222). Enforcement measures shall be carried out by States in accordance with their adopted national instruments (pursuant to Article 212, Paragraph 1), as well as this

Convention. Besides, national implementation shall be ensured by States to make those established international instruments applicable, for the ultimate purposes as mentioned above. In connection with these aspects regarding air pollution from vessels, there are interfaces between several provisions of UNCLOS and MARPOL; for instance, the MARPOL Convention, Annex VI – Regulation for the prevention of air pollution from ships, and in particular, Regulation 16 concerning shipboard incineration (IMO, 1973), which is also relevant in terms of incineration of plastic waste.

2. The International Convention for the Prevention of Pollution from Ships (MARPOL)

One of the "four pillars" of the international framework, which regulates maritime safety and security, maritime education and training, certification and watchkeeping, the protection of marine environment and the prevention of marine pollution, as well as the conditions of working and living, and other social aspects for seafarers, is the International Convention for the Prevention of Pollution from Ships (MARPOL). The Convention has six annexes with provisions stipulating the prevention, reduction, and control of pollution from ships by oil, noxious liquid substances in bulk, harmful substances in packaged form, sewage, garbage, and air pollution (IMO, 1973). In particular regarding marine plastic pollution (MPP), this Dissertation discusses related matters within Annex V of the Convention, which establishes regulations for the prevention of pollution by garbage from ships. The Annex has three chapters and two appendixes. In detail, Chapter 1 establishes general provisions; Chapter 2 stipulates provisions regarding the verification of compliance with this Annex; and Chapter 3 establishes provisions clarifying some aspects in connection with the International Code for Ships Operating in Polar Waters (Polar Code). Moreover, Appendix I establishes criteria to classify solid bulk cargoes as harmful to the marine environment; and Appendix II establishes the form of the ship's Garbage Record Book.

In the first place, the Convention and some particular articles thereof (as per the Author's consideration) will be reviewed. Totally, there are twenty articles, which are mutually agreed among the Parties to the Convention. It is important to mention about the need of the preservation of the human environment in general and the marine environment in particular, which is placed at the first consciousness of the Parties to the Convention. Also, it is recognized that, not only oil, but also other harmful substances from vessels when being released, either deliberately, negligently, or accidentally into the marine environment causes a "serious source of pollution". Besides, all Parties express their desire in completely eliminating intentional pollution of the marine environment by the above-mentioned substances, as well as in minimizing accidental discharge of those substances. Article 1 stipulates the general obligations under the Convention, in which an effective implementation of the provisions of this Convention and its specific Annexes (which are accepted by Parties) shall be undertaken for the purposes of the prevention of marine pollution arising from or in connection with any discharge or effluents of harmful substances regulated by the Convention. Some terms are clearly defined in Article 2, for instance, *inter alia*, "harmful substance" and "discharge". For the purposes of this Convention, "harmful substance" includes any substance, which causes hazards or harmful effects to human health, marine life, the marine environment, or interferes with other authorized utilization of the sea; as well as those substances under the control of this Convention. The definition of "discharge" includes any actions of, *inter alia*, releasing, disposing, emitting, emptying, escaping, leaking, pumping, or spilling harmful substance or effluents containing those substances. In the same paragraph of this Article, the action of "dumping", which is defined as in the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention), as well as other two type of release activities are excluded from the definition of "discharge".

Regarding the application of the Convention, Article 3 requires that all vessels, which are registered under the flag or the authority of a Party to this Convention, shall comply with the provisions of this Convention. Besides, provisions regarding the

sovereign rights of the Parties and the application exceptions are also established in this Article.

Article 4 requires the Administration, i.e., the Government of the flag State, shall ensure the prohibition and sanctions of any violation of the requirements in accordance with this Convention through their national law, regardless of the place of violation. Following sufficient evidence of a case, proceedings shall be instituted pursuant to their national law. In case of port States and coastal States, in which such violation occurs within the waters under their jurisdiction, those States shall prohibit and establish sanctions for such violation pursuant to their respective national laws. Following such prohibited violation, there shall be the institution of proceedings, and the reporting of information and relevant evidence to the flag State of the violated vessel. Afterwards, the flag State is obliged to take remedy action accordingly, as well as to promptly inform the reporting Party and the Organization. The last paragraph of this Article establishes requirement for the adequacy and equality of the penalties' severity pursuant to the Party's national law, regardless of the place of violation, for the purpose of discouragement of such violations.

The next article stipulates requirements with regards to the issuance of certificates pursuant to the provisions of this Convention under the authority of a Party (Article 5). In detail, an issued certificate shall be accepted and treated with equal validity and purposes and without discrimination, regardless of the issuing Party. Upon the arrival of a vessel, which is obliged to carry on board a certificate as described above, authorized officers of the port State may conduct inspection for verifying the existence of a valid certificate. In case of "clear grounds" or an absence of a valid certificate, further actions shall be carried out to prevent the vessel from sailing. The permission for the vessel to continue proceeding to sea is granted only when either corrective actions are performed and there is not any "unreasonable threat of harm to the marine environment" presented by that vessel, or the purpose of sailing is for proceeding to an appropriate and available shipyard at the nearest distance for repairing. The third paragraph of this Article establishes requirements regarding the communication and consultation between the port State and the flag State of the vessel

in case of a denial of arrival issued by or any actions against the vessel taken by that port State when the provisions of this Convention are not complied by that vessel. The last paragraph of this Article requires Parties to apply the principle of "no more favourable treatment" with respect to the application of the provisions pursuant to this Convention to those vessels, which are registered under the flag or authority of non-Parties to the Convention.

The following article regulates requirements with regard to the cooperation between the Parties to this Convention in terms of the violation detection and the enforcement of the provisions (Article 6). Accordingly, in their cooperation all practicable and appropriate measures shall be utilized, including, *inter alia*, detection methods, environmental monitoring, reporting procedures, as well as procedure for evidence collection. An inspection to a vessel for the verification of any discharge violation may be carried out by authorized or appointed officers of a port State. In case of a detected violation following that inspection, a report regarding any action taken shall be submitted to the flag State of that vessel. Also, information regarding evidence of discharge violation shall be furnished to the flag State, and notification shall be submitted to the master of the violated vessel by the reporting State. Following this reporting procedure, investigation shall be conducted by the flag State with further cooperation with the reporting Party. In case of sufficient evidence, proceedings shall be instituted pursuant to their national laws, and prompt communication regarding the action taken shall be submitted to the reporting Party, as well as to the Organization. In other circumstance, when a report and evidence are submitted from a third Party, an inspection of discharge violation may be also conducted to a vessel by a port State. In this case, the port State shall submit a report of the inspection to the requesting Party and the flag State for the appropriate action to be taken in accordance with this Convention.

The next article for reviewing as per the Author's consideration is Article 8 regarding reporting of incidents in connection with harmful substances. The Convention requires that any incident report shall be submitted without delay and to the fullest extent as possible. Particularly, this Article establishes provisions in

accordance with Protocol I to the Convention, and *vice versa*. Accordingly, all necessary arrangements shall be established by each Party in terms of an appropriate officer or agency for receiving and processing of all incident reports. Following their establishment, complete details regarding these arrangements shall be submitted to the Organization, and other Parties and the Member States of the Organization are to be circulated thereafter. The third paragraph of this Article establishes requirements regarding further relaying of the report upon receiving to the flag State and other affected State. The last paragraph requires that instructions for maritime inspection vehicles and other services regarding reporting procedures and requirements shall be issued by each Party. Regarding Protocol I to the Convention, there are five articles, ranging from the duty and the occasion to report, the contents and supplementary of the report, as well as the reporting procedures.

It is important to note that, Annex V to the Convention regarding the prevention of pollution by garbage from vessels is one of the Optional Annexes according to Article 14. This means that a State may declare that they do not accept and thereby they are not bound by these Optional Annexes, either one or all.

In accordance with Article 17 regarding the promotion of technical cooperation, support for those Parties requesting technical assistance, shall be promoted by the Parties to the Convention, consulting the Organization and other international organizations, and assisting and coordinating by the United Nations Environment Programme. The mentioned technical cooperation includes, *inter alia*, training in technical and scientific matters, research, the provision of equipment and facilities, as well as other arrangements and measures for the prevention and mitigation of marine pollution from vessels.

Following the review of the Convention and some particular articles thereof, the Dissertation will review Annex V to the Convention concerning the regulations for the prevention of pollution by garbage from vessels. In particular, aspects regarding the provisions in connection with MPP will be concentrated. As mentioned above, this Annex has three chapters with fourteen regulations, and two appendixes. The first regulation provides nineteen definitions for the purposes of this very Annex, including,

inter alia, cargo residues, domestic wastes, en route, fishing gear, fixed and floating platforms, garbage, incinerator ashes, operational wastes, plastic, special area. Some definitions regarding or in connection with MPP discussion will be reviewed. First of all, "domestic wastes" are those generated by the crew from the accommodation spaces on board the vessels. According to the personal experience and observation from the Author as a former seafarer, domestic wastes are a mixture of garbage or trash, including food waste, packaging materials, and especially, plastics, among other things. Secondly, "fishing gears" are focused due to the discussion regarding the abandoned, lost, or otherwise discarded fishing gear (ALDFG) at sea, which significantly contribute to the MPP issues. Thirdly, the definition "garbage" includes all kinds of, *inter alia*, all plastics in the first place, domestic wastes, operational wastes, cargo residues, incinerator ashes, fishing gear. Fourthly, "incinerator ashes" are those final products of clinkers and ash following the process of shipboard incineration of garbage. Fifthly, and the most importantly in terms of this Dissertation, the definition of "plastic" includes all solid materials containing one or more "high molecular mass polymers", e.g., *inter alia*, all garbage consisting of plastic in any form, plastic garbage bags, synthetic ropes, synthetic fishing nets, and incinerator ashes from plastic wastes. This definition also mentions about the manufacture and fabrication methods, as well as the characteristics of the materials. Sixthly, "special area" is a sea area by the virtue of its oceanographic and ecological conditions, and its maritime traffic features, and due to recognized technical challenges, special mandatory requirements to prevent marine pollution by garbage from vessels are adopted therein. One of the special areas will be focused within the scope of this Dissertation is the North Sea area, which consists of the North Sea and its seas, the English Channel, and the Skagerrak. Specific and precise latitude and longitude coordinates of the area boundary are provided in Paragraph 14(6) of this Regulation.

Regarding the application of Annex V, Regulation 2 requires that all vessels shall comply with the provisions of this Annex.

Regulations 3, 4, 5, and 6 establish requirements regarding the prohibition requirements and related conditions of the discharge of garbage in particular areas of

concern. Also, these regulations refer to exceptions stipulated either in internal links (e.g., Regulation 7, Appendix I of Annex V) to this Convention or external references to other instruments. Table S5 below will summarize the provisions of these regulations with the perspectives of MPP discussion.

Table S5

MARPOL, Annex V: Provisions regarding the prohibition requirements and related conditions of the discharge of garbage in particular areas of concern

Regulation	**Area of concern**	**Discharge of garbage**	**Exceptions, Internal links, External references**
Regulation 3	Into the sea	All garbage: Prohibited.	Exceptions link internally to Regulations 4, 5, 6, and 7; Exceptions link internally to Regulation 13.1 (Equivalent to: Exceptions refer externally to the Polar Code, Part II-A, Section 5.2).
		All plastics: Prohibited.	Exceptions link internally to Regulation 7.

Regulation 4 (as amended by Resolution MEPC.277(70) adopted on 28 October 2016)	Into the sea; Outside special areas.	Cargo residues (with specific conditions): Only permitted when en route; $D \geq 12\ nm$.	Specific criteria link internally to Appendix I of this Annex.
		Solid bulk cargo: Requirements regarding classification and declaration.	Definition links externally to SOLAS Convention, Regulation VI/1-1.2.
		Mixed or contaminated garbage: More stringent requirements.	
Regulation 5	Into the sea; From fixed or floating platforms.	Any garbage: Prohibited.	
Regulation 6 (The structures of this Regulation and Regulation 4 are different, which requires	Into the sea; Within special areas.	Cargo residues (with specific conditions): Only permitted when en route;	Specific criteria link internally to Appendix I of this Annex;
		Solid bulk cargo: Requirements	Definition links externally to SOLAS

further discussion.)	regarding classification and declaration; Requirements regarding the port of departure and the next port of destination, and the absence of adequate reception facilities; $D \geq 12\ nm$. Mixed or contaminated garbage: More stringent requirements.	Convention, Regulation VI/1-1.2.

Strictly stipulating, Regulation 3 establishes general prohibition on discharging garbage into the sea, with exceptions pursuant to either the internal links to Regulations 4, 5, 6, and 7; or the internal link to Regulation 13.1, which is equivalent to the external reference to the Polar Code, part II-A, Section 5.2. Within the scope of this Dissertation, it is of particular importance to highlight that, all plastics, including, *inter alia*, synthetic ropes and fishing nets, plastic garbage bags, and incinerator ashes from plastic products, are prohibited from discharging into the sea, with some exception cases pursuant to Regulation 7. Similarly, any garbage, including plastic wastes, from fixed or floating platforms, as well as from all vessels moored therein or within the radius of 500 meters from those platforms (Regulation 5), is prohibited.

Regulation 4 and Regulation 6 stipulate requirements regarding discharge of garbage in terms of either outside or inside special areas, respectively. There is one difference in terms of the structure of these provisions. In other words, in Regulation 4, the requirements regarding definition, classification, and declaration for solid bulk cargo are positioned as Paragraph 3 under this Regulation; whereas, in Regulation 6, the same requirements are positioned as Subparagraph .2.2 under Paragraph 1 of this Regulation. In detail, according to the perspectives and interpretation of the Author of this Dissertation, in terms of Regulation 4, Paragraph 3 establishes a connection with Appendix I of this Annex, regarding the criteria for classifying solid bulk cargo as harmful substance to the marine environment. Whereas, in terms of Regulation 6, these requirements regarding solid bulk cargo are listed as required conditions for discharging of cargo residues into the sea inside special areas.

Besides the above-mentioned difference between these regulations, the discussion continues with each of their requirements. In detail, Regulation 4 requires that cargo residues shall only be permitted to discharge outside special areas while the vessel is underway with the minimum distance of 12 nautical miles from the nearest land. Other conditions for discharge permission include the impossibility of recovering utilizing "commonly available methods for unloading", and the absence of any harmful substances to the marine environment pursuant to the criteria in Appendix I of this Annex. It is important to highlight the amendments to Annex V pursuant to Resolution MEPC.277(70), which is adopted on 28 October 2016 (IMO, 2016b). These amendments include a new appendix with requirements regarding harmful substances to the marine environment (HME), as well as the addition of new paragraphs or subparagraphs in connection with this new appendix, and the amendments to the existing appendix regarding the garbage record form. In detail, Appendix I of Annex V, in accordance with the classification criteria of the United Nations Globally Harmonized System of Classification and Labelling of Chemicals (GHS), lists several parameters to determine whether cargo residues of solid bulk cargoes are harmful to the marine environment. Among these criteria, and within the scope of this Dissertation, Subparagraph 7 clearly determines solid bulk cargoes,

which consist of or contain, *inter alia*, synthetic polymers, plastics, rubber, or plastic feedstock pellets, including chopped, macerated, milled, shredded, or similar materials, as of cargo residues harmful to the marine environment. Continuing with the discussion regarding Regulation 4, other requirements in terms of solid bulk cargoes, which are defined as in the SOLAS Convention, Regulation VI/1-1.2, include the classification according to Appendix I as mentioned above, and the declaration about their harmful effects to the marine environment (if any) by the shipper. In addition, Paragraph 4 of this Regulation requires that more stringent measures are applied to mixed or contaminated garbage, of which the affecting substances are prohibited from discharging or different discharge requirements are applied to those substances.

Regarding Regulation 6 – Discharge of garbage within special areas, similarly, cargo residues shall only be permitted for discharging into the sea within special areas when the vessel is underway and with the satisfaction of all other conditions. These conditions include the absence of any substances harmful to the marine environment (pursuant to Appendix I as mentioned above) in cargo residues contained in water after washing cargo holds. Besides, the second condition to be satisfied is about the definition, classification, and declaration of solid bulk cargoes, similar as mentioned above. The next conditions in connection with MPP discussion are established in Subparagraphs .2.4 to .2.6, including the requirements regarding the ports of departure and arrival, as well as the vessel's transit between these ports being within the special area; and the absence of adequate reception facilities at those ports; and the minimum distance of discharging hold washing water containing cargo residues of 12 nautical miles from the nearest ice shelf or the nearest land. Similar to Paragraph 4 of Regulation 4, Paragraph 4 of Regulation 6 also requires the application of the more stringent requirements in case of mixed or contaminated garbage.

Regulation 7 establishes exception cases, in which the application of Regulations 3, 4, 5, and 6 of Annex V, and the Polar Code, Part II-A, Section 5.2 shall not be required. In general, these exception cases include the discharge of garbage for the purpose of ensuring the safety of the vessel, its crew and equipment, as well as for

saving life at sea; Similarly, in terms of the discharge of fishing gear, besides those mentioned purposes, there is an addition of an important purpose of the protection of the marine environment; Furthermore, the accidental losses of garbage and fishing gear (with specific conditions) are also included in these exception cases.

Regarding the reception facilities, Regulation 8 requires that adequate reception facilities shall be provided at each Party's ports and terminals for garbage reception. These facilities are required to be appropriate to the needs of those vessels disposing garbage to them, and not to cause undue delay to the operations of those vessels. The next two paragraphs of this Regulation establish requirements for reception facilities within special areas and in regional arrangements. In detail, Paragraph 2 requires that adequate reception facilities shall be, as soon as possible, provided in all of each Party's ports and terminals within the special area, which borders the coastline of that Party. The notifications regarding mentioned measures taken by the Party concerned shall be submitted to the Organization. Consequently, a date of entering into force of Regulation 6 with regard to the notified area shall be established by the Organization; as well as shall be notified to all Parties. Until that established date, Regulation 4 is applied to vessels navigating in a special area. According to the third paragraph of this Regulation, regional arrangements, in which a Regional Reception Facilities Plan shall be developed considering the Organization's guidelines, may be participated by Small Island Developing States, due to their specific circumstances, and due to the fact of those practical means to comply with the requirements of this Regulation. In the same paragraph, there are other requirements regarding the consultation to the Organization for circulating to other Parties with regards to regional Arrangement, as well as the notification in case of inadequacy of the provided facilities.

Regulation 9 establishes provisions for the Port State control inspection on operational requirements. In detail, upon arrival in a port or an offshore terminal of a Party, officers authorized by that Party may conduct inspection on that vessel with regards to operational requirements in accordance with Annex V, in case of "clear grounds" on the circumstances of the lack of the crewmembers' familiarization with important shipboard procedures for the prevention of marine pollution by garbage

from vessels; as well as the procedures pursuant to Article 5 of this Convention. The violated vessel shall not be permitted to proceed to sea until the situation has been corrected pursuant to the requirements of Annex V.

The requirements regarding placards, garbage management plan, and garbage record book are stipulated in Regulation 10. Table S6 below summarizes those requirements.

Table S6

MARPOL requirements regarding placards, garbage management plan, and garbage record book

Requirements regarding	**Vessel categories**	**Specific requirements**	**Internal links, External references**
Placards	Vessels: $LOA \geq 12\ m$; Fixed or floating platforms.	Placards shall be displayed to notify the crew and passengers of the discharge requirements; Language: working language; Additional condition applied for additional language.	Pursuant to Regulations 3, 4, 5, and 6 of Annex V; The Polar Code, Part II-A, Section 5.2.
Garbage management plan	Vessels: $GT \geq 100$;	A garbage management plan,	The Organization's Guidelines

	$\Sigma_{pax} \geq 15$ persons; Fixed or floating platforms.	shall be carried on board; The crew shall follow the plan; The plan includes procedures to minimize, collect, store, process, and dispose garbage, as well as utilize related equipment; designated person(s) on board for carrying out the plan; Language: working language.	
Garbage Record Book	Vessels (engaged in international voyages): $GT \geq 400$; $\Sigma_{pax} \geq 15$ persons; Fixed or floating platforms.	A Garbage Record Book, shall be provided; Approved form: Either as a part of the vessel's official logbook, or as an electronic record book; or Specified form: Appendix II.	Appendix II – Form of Garbage Record Book

Under Paragraph 3 regarding a vessel's Garbage Record Book (GRB), there are six subparagraphs establishing requirements for garbage record-keeping and the relevant preservation of the book and its receipts. The provisions distinguish several types of discharge-related entries into GRB. In detail, prompt recorded entry for any discharge into the sea in general, to a port reception facility or another ship, and a completed incineration, shall be made into GRB. Also, the signatures for the date and each completed page shall be made. Requirements regarding language of entries are also established in Subparagraph 3.1. In addition, for entries of discharges into the sea pursuant to Regulations 4, 5, and 6, or the Polar Code, Part II-A, Section 5.2, and to a port reception facility or another ship, and a completed incineration, or in case of any discharge or accidental loss pursuant to Regulation 7, more specific entry information is required in accordance with Subparagraphs 3.2, 3.3, 3.4, and 3.6. In terms of the mentioned accidental loss or discharge of fishing gear, which causes a significant threat to the marine environment or navigation, a report shall be submitted to the flag State and the coastal State. Regarding the preservation period, it is required that the Garbage Record Book and its related receipts issued from respective reception facilities to be kept on board for inspection.

Regarding inspection of a vessel upon its arrival at a Party's port or offshore terminal, the Garbage Record Books or a vessel's official logbook may be inspected by the competent authority of that Party. There are also requirements regarding the validity of the true copy from those documents, which may be submitted for any judicial proceedings.

Chapter 2 of Annex V establishes provisions regarding the verification of compliance with this Annex. In detail, Regulation 11 requires that the IMO Instruments Implementation Code (III Code) shall be applied for the purpose of execution of Parties' obligations and responsibilities pursuant to this Annex.

Regulation 12 establishes requirements regarding, *inter alia*, periodic audits by the Organization, the audit standard, the Audit Scheme, the facilitation of conducting the audit, and the implementation of the programme of actions following the addressed findings, as well as an overall schedule for auditing of all Parties.

Chapter 3 of Annex V provides an external connection between the provisions of this Annex and the environment-related provisions of the Polar Code, including its introduction and Part II-A, Chapter 5. In detail, Regulation 13 provides the definitions of the terms "Polar Code", "Artic waters", and "Polar waters". Regulation 14 establishes a mutual application as mentioned above, in which the environment-related provisions of the Polar Code, in addition to applicable requirements under Annex V, shall be complied by all vessels pursuant to this Annex, operating in polar waters.

3. The International Convention for the Safety of Life at Sea (SOLAS)

Maritime safety and protection of the marine environment are two of the main concerned matters within the purposes of the International Maritime Organization (IMO, 1948; Vuong, 2023a). This part will discuss the relations between the maritime safety and security and the protection of the marine environment. As discussed previously, UNCLOS highlights the particular importance of maintaining the seaworthiness of vessels for the purpose to prevent damages to the marine environment, pursuant to Article 219 (UN, 1982). Similarly, UNCLOS also emphasizes the importance of enforcement measures to prevent pollution to the marine environment and further developing major harmful consequences arising from or in connection with maritime casualties (Article 221), including, *inter alia*, collision, stranding, navigational incidents, and other shipboard occurrences.

The International Convention for the Safety of Life at Sea (SOLAS) establishes provisions addressing safety risks for vessels engaged in maritime transport, e.g., fire and explosion, collision, stranding, structural failure, and flooding (IMO, 1974; Vuong, 2023d). The baseline for this discussion can be focused on the desire of the Contracting Governments to the SOLAS Convention, which is to promote "safety of life at sea". From this perspective of "safety of life", national laws and regulations, *inter alia*, shall be promulgated by the Contracting Governments for the full, complete, and effective implementation of the Convention (Preamble, Article I); and ultimately, for ensuring that their vessels are "fit for service" for which they are intended. Equally

important, the roles of maritime casualty investigation conducted by each Administration are also highlighted pursuant to Chapter I, Part C, Regulation 21. SOLAS emphasizes that by conducting such investigation, possible or desired changes in the present regulations may be determined.

In connection with the protection of the marine environment in general, and the MPP discussion in particular, several SOLAS chapters, including, *inter alia*, ship-based and shore-based requirements, can be mentioned. In detail, Chapter II establishes requirements regarding the construction of ships, including, the design, building, and maintenance. The specific provisions of this Chapter promulgate requirements ranging from vessels' structure, subdivision, stability, machinery and electrical installations, as well as fire protection, fire detection, and fire extinction. Regarding safety of navigation, Chapter IV – Radiocommunication and Chapter V – Safety of navigation are to be considered. Those requirements are applied to not only vessels and their equipment, but also to Contracting Governments and communication service providers (as to Chapter IV), and navigation-related services (as to Chapter V). Regarding the carriage of cargoes in general, there are Chapter VI – Carriage of cargoes and oil fuels, Chapter VII – Carriage of dangerous goods, and Chapter XII – Additional safety measures for bulk carriers, of which their provisions can be considered, including requirements for carriage of solid bulk cargoes (in connection with those containing or consisting of synthetic polymers, plastics, rubber, or plastic feedstock pellets in any of their forms), loading, unloading, stowage, and securing, and in particular, additional requirements for bulk carriers, e.g., *inter alia*, damage stability requirements, and structural strength. Furthermore, SOLAS requires shipping companies to comply management requirements for the safe operation of their vessels. In this regard, the IMO's International Management Code for the Safe Operation of Ships and for Pollution Prevention or the International Safety Management Code (ISM Code) and the requirements thereof shall be complied by the shipping companies and their vessels. Other chapters may be assessed further in terms of the interrelations between the protection of the marine environment and the maritime safety and security.

4. The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978 (STCW Convention)

It is of paramount importance to reaffirm the mutual desire of the Parties to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978 (STCW Convention), in which, not only the safety of life and properties at sea, but also, and in particular, the protection of the marine environment, can be promoted by establishing commonly agreed international standards in matters concerned (IMO, 1978). With this paramount desire, those Parties have mutually agreed the general obligations, in which all of their national laws and regulations, and other necessary measures shall be promulgated for a full, complete, and effective implementation of this Convention. Consequently, the qualification and fitness for duties of seafarers for shipboard services shall be ensured by those Parties, accordingly.

Similarly, the importance of the establishment of detailed mandatory standards of competence and other mandatory requirements are also recognized by the 2010 Manila Conference, in which proper maritime education and training, adequate experiences, skills, and competence of duty performance are required to all seafarers for the purposes of maritime safety and security and the protection of the marine environment. As a matter of fact, the Conference also recalled a statistic, which shows that human error causes or associates with a significant percentage of pollution incidents and maritime casualties. The Conference reaffirmed that maintaining "the highest practicable standards of training, certification and competence" with regard to the seafarers employed on seagoing vessels is the one effective approach to reduce the risks in connection with the above-mentioned human error. Ultimately, with desire in achieving and maintaining "the highest practicable standards" for the protection of the marine environment, maritime safety and security, both at sea and in port, the Amendments to the Seafarers' Training, Certification and Watchkeeping (STCW) Code was adopted by the Conference.

In general, pursuant to Part A of the STCW Code, mandatory standards of competence are categorized into seven functions; namely, navigation, cargo handling and stowage, controlling the operation of the ship and care for persons on board, marine engineering, electrical, electronic and control engineering, maintenance and repair, radiocommunications (IMO, 1995). With regards to the protection of marine environment in general and the MPP discussion in particular, Table S7 summarizes those related standards of competence under several specific functions, and at different levels of responsibility; namely, management level, operational level, and support level. It is important to note that, from the perspectives of the protection of the marine environment and the prevention of marine pollution in general, and the MPP discussion in particular, the summarized standards are, *inter alia*, either environment-related or in connection with the relations between maritime safety and security versus the protection of the marine environment. Besides, as generally, each table (from A-II/1 to A-II/5, and A-III/1 to A-III/7) of the STCW Code specifies the minimum standard of competence for specific rank on board vessels, for example, *inter alia*, senior deck officers and engineer officers, officers in charge of a navigational watch or an engineering watch, as well as deck, engine, or electro-technical ratings in their levels of responsibility, respectively. Because of the mentioned perspectives, the combined table below will concentrate on the particular functions, respective competence, knowledge, understanding, and proficiency (KUP), as well as the evaluating criteria (if any) for each level of responsibility.

Table S7

STCW standards of competence under specific grouped functions, and at different levels of responsibility

Functions of competence standards	**Levels of responsibility**		
DECK DEPARTMENT	**Management level**	**Operational level**	**Support level**

Navigation	Establishing and maintaining watchkeeping procedures and arrangements, including, *inter alia*, KUP in thorough knowledge and application of the International Regulations for Preventing Collisions at Sea, 1972 (COLREG), as amended; to ensure compliance with international regulations and guidelines for the purposes of the safety of navigation, the vessel, and safety of life, as well as the protection of the marine environment; etc.	Maintaining a safe navigational watch, including, *inter alia*, KUP in watchkeeping, thorough knowledge and application of the International Regulations for Preventing Collisions at Sea, 1972 (COLREG), as amended; the use of ships' routeing systems, etc.	Contributing to a safe navigational watch in general; Contributing to monitor and control a safe watch, including, *inter alia*, KUP in basic procedures for the protection of the marine environment.
Cargo handling and stowage	Planning and ensuring safe loading, stowage, securing, unloading of cargo, as well as inspection during the voyage, including, *inter alia*, KUP in the effect of cargo and cargo	Monitoring the loading, stowage, securing, and unloading of cargoes, as well as inspection during the voyage, including, *inter alia*, KUP in the effect of cargo in general on	Contributing to cargo and store handling in general.

	operation on the vessel's seaworthiness and stability; in establishing procedures for safe handling of cargo in compliance with relevant instruments, e.g., IMDG Code, IMSBC Code, MARPOL, etc.	the vessel's seaworthiness and stability, etc.	
Controlling the operation of the ship and care for persons on board	Monitoring and controlling compliance with legislative measures and requirements for maritime safety and security, and the protection of the marine environment, including, *inter alia*, KUP in international maritime law, international agreements and conventions, certificates and documents, responsibilities under LL Convention, SOLAS Convention, COLREG; especially, aids and methods for pollution prevention	Ensuring the compliance with pollution-prevention requirements, including, *inter alia*, KUP in prevention of marine pollution and anti-pollution procedures; and fully observing MARPOL requirements; Maintaining positive environmental reputation by actions; Maintaining seaworthiness of the vessel, including, *inter alia*, KUP in ship stability and ship construction; etc.	Applying precautions and contributing o the prevention of marine pollution; Observing at all times the designed procedures for safeguarding the marine environment;

	of the marine environment from vessels, as well as national implementation of international instruments; etc.	Monitoring the compliance with legislative requirements, including, *inter alia*, KUP in basic working knowledge of relevant IMO conventions regarding maritime safety and security, and the protection of the marine environment.	
ENGINE DEPARTMENT	**Management level**	**Operational level**	**Support level**
Marine engineering	Generally, managing and ensuring safe operations and avoiding pollution to the marine environment;	Generally, ensuring safe operations and avoiding pollution to the marine environment;	Generally, contributing in ensuring safe operations and avoiding pollution to the marine environment;
Electrical, electronic and control engineering	-	-	-
Maintenance and repair	Ensuring safe working practices in accordance with legislative requirements, practices, permits to work, and	-	-

	environmental concerns.		
Controlling the operation of the ship and care for persons on board	Monitoring and controlling compliance with legislative measures and requirements for maritime safety and security, and the protection of the marine environment, including, *inter alia*, KUP in international maritime law, international agreements and conventions, certificates and documents, responsibilities under LL Convention, SOLAS Convention, COLREG; especially, aids and methods for pollution prevention of the marine environment from vessels, as well as national implementation of international instruments; etc.	Ensuring the compliance with pollution-prevention requirements, including, *inter alia*, KUP in prevention of marine pollution and anti-pollution procedures; and fully observing MARPOL requirements; Maintaining positive environmental reputation by actions; Maintaining seaworthiness of the vessel, including, *inter alia*, KUP in ship stability and ship construction; etc. Monitoring the compliance with legislative requirements, including, *inter alia*, KUP in basic working knowledge of relevant IMO conventions regarding maritime safety and security,	Applying precautions and contributing o the prevention of marine pollution; Observing at all times the designed procedures for safeguarding the marine environment;

	and the protection of the marine environment.

Besides, pursuant to Chapter VI of this Code, all crewmembers before joining a vessel for shipboard duties are required to complete basic training, including, *inter alia*, social responsibilities regarding environment-related competence. The qualification received for this approved basic training or instruction shall be maintained and refreshed every five years in accordance with the provisions of this Chapter. Regarding environment-related specification of minimum standards, pursuant to Table A-VI/1-4, seafarers are required to have competence in taking precautions for pollution prevention to the marine environment. With this regard, required KUP include basic knowledge concerning the impact and effects of the shipping industry, any operational or accidental pollution on the marine environment, and the diversity and complexity thereof, as well as basic procedures for environmental protection. Also, it is required to observe at all times the designed procedures for safeguarding the marine environment.

5. The Maritime Labour Convention, 2006 (MLC Convention)

The relations between the Maritime Labour Convention, 2006 (MLC Convention) versus maritime safety and security, and the protection of the marine environment can be discussed from the point of view of human element and human error contributing to maritime casualties, which, in turn, may cause or relate to pollution to the marine environment. With this regard, the human element and its important role in the prevention of maritime casualties have been acknowledged by the IMO (2003). Consequently, the issues related to the human element receive high priority in the work programme of the Organization, with the vision to improve performance; and in the result, the maritime safety and security, and the protection of the marine environment will be significantly enhanced. Similar to the mentioned vision, the IMO's strategic direction SD6: Address the human element (IMO, 2021b)

includes relevant issues, *inter alia*, human-centered design, fatigue management, and fair treatment of seafarers. In particular, the Organization highlights that fatigue causes negative impacts on the health, occupational safety, and well-being of the seafarers; and consequently, this state of extreme tiredness or exhaustion presents risks to not only health and safety of life, but also property and security, and more importantly, to the protection of the marine environment (IMO, 2019a).

The discussion now focuses on the MLC Convention with these mentioned perspectives. In the first place, the preamble of the Convention reaffirms the consciousness of the 2006 General Conference of the International Labour Organization (ILO) regarding the core mandate of the ILO in promoting the decent conditions of work, taking into account the global nature of the shipping industry and the need of seafarers for special protection (ILO, 2006). With these considerations, the Conference recalled the international standards pursuant to the SOLAS Convention, the STCW Convention, and COLREG, as well as the general legal framework under UNCLOS. Strictly stipulating, Article I of the Convention promulgates general obligations, pursuant to which "the right of all seafarers to decent employment" shall be ensured through complete effectiveness of implementation and enforcement of its provisions. In detail, Article IV requires that these rights of all seafarers shall be ensures, including, safe and secure workplace in compliance with safety standards, fair employment terms, decent living and working conditions on board vessels, as well as health and medical care, welfare supports, and other social rights. In particular, and in connection with fatigue-related aspects, the IMO's Circular MSC.1/Circ.1598: Guidelines on fatigue reviews several regulations of the MLC Convention stipulating matters concerns, including, *inter alia*, regulated working and resting hours, adequate leave, appropriate manning levels, decent accommodation and recreational facilities on board, good-quality food and drinking water with regulated hygienic conditions, occupational safety and health (IMO, 2019a). All in all, the requirements pursuant to the MLC Convention's provisioned contribute to protect the seafarers and their rights, and as the results, will improve performance, contributing to maritime safety and

security, and especially, to the protection of the marine environment and the prevention of pollution thereof.

6. The IMO Instruments Implementation Code (III Code)

By adopting the IMO Instruments Implementation Code (III Code), the Organization highlights the importance and dependance of those factors on the "ultimate effectiveness" of an instrument, including, among other things, all States becoming party to all instruments (concerning maritime safety and security, and the protection of marine environment and the prevention of pollution thereof), the full and effective implementation and enforcement of those instruments, the reporting procedures to the Organization (IMO, 2013b). In accordance with the Code, the instruments under its scope include the SOLAS Convention, the LL Convention and its 1988 Protocol, the MARPOL Convention and its 1978 and 1997 Protocols, the STCW Convention, the TM Convention, and COLREG, which are also in accordance with the objective of this Code pursuant to the common areas applied to flag States, port States, and coastal States. In connection with the on-going discussion regarding the prevention of pollution of the marine environment in general and the MPP-related aspects, Table S8 summarizes the responsibilities and obligations of States following each part of the Code.

Table S8

The responsibilities and obligations of States under the III Code

Responsibilities and obligations	FLAG STATE	PORT STATE	COASTAL STATE
Common areas	An overall strategy is recommended to be developed to fulfill international obligations and responsibilities as a flag, port, or coastal State. This strategy is monitored and assessed by an established methodology to effectively implement and enforce those international mandatory instruments. Also, the strategy is continuously reviewed to		

ensure that the performance and capacity as a flag, port, or coastal State is achieved, maintained, and improved.

Pursuant to the provisions of the treaty law and the IMO's conventions, State should establish, *inter alia*, national laws and regulations for their national implementation of international instruments, a legal basis for enforcing those instruments. For these purposes, sufficient personnel with maritime expertise are required.

The above-mentioned strategy and national legislation should be communicated to all stakeholders concerned.
Also, the evidence of conformity to those mentioned instruments and the effective performance of a State should be appropriately recorded following a documented procedure.

Particularly important, a State's performance (through their effective implementation and enforcement, as well as monitoring of compliance) should be continuously improved. This can be achieved through an improvement culture (in terms of maritime safety, environmental protection, and pollution prevention), which includes training and drills on the matters concerned, and incentive mechanisms for seafarers and shipping companies. Besides, proactive measures should be carried out in terms of recurrence prevention, non-conformities' causes, corrective actions, and potential non-conformities.

Responsibilities and obligations	*FLAG STATE*	*COASTAL STATE*	*PORT STATE*
Implementation	Besides general obligations and responsibilities as described in the common areas, resources and processes should be established for the	Besides general obligations and responsibilities as described in the common areas, national legislation, guidance, and procedure of a coastal	Besides general obligations and responsibilities as described in the common areas, the Code highlights the "integral role" of port States in achieving

administration of a maritime safety and environmental protection programme, including, *inter alia*, administrative instructions for the implementation of applicable international instruments, an independent audit and inspection programme, compliance with international standards of training, certification, and watchkeeping of seafarers, casualty investigation, and sufficient and efficient manning levels.	State should be established to consistently implement and verify their rights, obligations, and responsibilities pursuant to relevant international instruments. Those mentioned rights, obligations, and responsibilities include (mostly navigation-related services), *inter alia*, aids to navigation, hydrographic services, meteorological services and warnings, radiocommunication services, search and rescue services, ship's routeing and ship's reporting systems, and vessel traffic services.	maritime safety, the protection of the marine environment, as well as pollution prevention. With this regards, national legislation, guidance, and procedure of a port State should be established to consistently implement and verify their rights, obligations, and responsibilities pursuant to relevant international instruments. Particularly important, in connection with the protection of the marine environment and the MPP discussion, those mentioned rights, obligations, and responsibilities includes, *inter alia*, the provision of adequate port reception facilities or acceptance capacity for all waste streams

			pursuant to the Organization's instruments, port State control, and register-keeping of fuel oil suppliers.
Enforcement	Enforcement measures should be taken by a flag State to ensure compliance with their international obligations. These measures include, *inter alia*, sailing prohibition in case of non-conformities, periodic inspections of their vessels, penalties with adequate severity for violation discouragement by vessels or individuals, institutions of proceedings following an investigation against violated vessels of individuals. An appropriate control and monitoring programme should be	An appropriate control and monitoring programme should be developed and implemented for the allocation of statistical data, pollution response mechanisms, and cooperation with flag States and port States in maritime casualty investigations.	Similarly, enforcement measures should be taken by a flag State to ensure compliance with their international obligations. With this regard, the Code requires port States to apply principle of "no more favourable treatment" in exercising their rights and fulfilling their obligations. Also, the Code reaffirms general requirements regarding the operations of the port State control officers. In detail, it is required to have an absence of commercial and financial interests, and other pressures, as well as any

	developed and implemented for casualty investigation and reporting procedures, the collection of statistical data, as well as a timely response to reports by port or coastal States regarding deficiencies and alleged pollution incidents.		connections with recognized organizations or classification societies, and any external influence on the inspection and control results.
Evaluation and review	A periodic evaluation of a flag State's performance in terms of international obligations should be carried out. The Code also includes measures for performance evaluation of flag States, and recommended areas for regular review.	(Similar to flag State's.)	(Similar to flag State's.)
Specific areas	**Delegation of authority** The surveys, inspections, audits, issuance of certificates and documents, vessels' marking, and other	–	–

	statutory work pursuant to the Organization's conventions are conducted by a recognized organization (RO) on behalf of a flag State to their vessels. An oversight programme for monitoring of and communicating with its RO should be established to ensure their full international obligations.
Flag State surveyors	The Code establishes minimum requirements for surveyors of personnel, who perform surveys, inspections, and audits on vessels or in companies pursuant to international mandatory instruments.
Flag State investigations	

The Code requires that impartial and objective investigators, who have appropriate working knowledge, practical experience, and expertise in specific areas, are responsible for conducting marine safety investigations. The Casualty Investigation Code, the Organization's relevant international instruments and guidelines are taken into account during conducting maritime casualties and reporting procedure thereafter.

Furthermore, in connection with the III Code, and with regards to the protection of the marine environment in general and the MPP discussion in particular, several relevant IMO's instruments can be discussed, including, *inter alia*, the IMO Member State Audit Scheme, the RO Code, the Casualty Investigation Code, the Procedures for port State control. First, the Framework and Procedures for the IMO Member State Audit Scheme (IMSAS) is adopted pursuant to Resolution A.1067(28) dated on 4 December 04, 2013 (IMO, 2013a). IMSAS utilizes the III Code as its audit standard, with the objective of determination of Member States' implementation and enforcement performance, and with the vision of promotion of the consistency and effectiveness of respective implementation of applicable IMO's instruments; as a

result, enhancing the global and individual Member States' performances. Second, pursuant to Resolution MSC.349(92) and Resolution MEPC.237(65), the Code for Recognized Organizations (RO Code) was adopted by the Organization, with the purposes to provide flag States international standard for assessment, recognition, and authorization of recognized organizations (IMO, 2013d). The scope of the RO Code includes, *inter alia*, SOLAS, MARPOL, and LL Convention. Third, the IMO recognizes the fact that maritime casualties and incidents continue to happen with results of loss of life and properties, and pollution of the marine environment (IMO, 2008) in their Resolution MSC.255(84) adopting the Code of the International Standards and Recommended Practices for a Safety Investigation into a Marine Casualty or Marine Incident (Casualty Investigation Code). According to the Code, the purposes are to timely and accurately report the maritime casualties for identification of the circumstance and the causal factor; consequently, safety issues can be addressed, and overall, maritime safety and the protection of the marine environment can be enhanced (IMO, 2008; IMO, 2013c). Fourth, regarding the port State control and their procedures, the Organization in their Resolution A.1155(32) recognizes the fact that port States through their efforts contribute to enhancing maritime safety and security, the protection of the marine environment, and the prevention of marine pollution (IMO, 2021a). In terms of MARPOL Annex V within the scope of port States' inspections, the Resolution establishes a list of detainable deficiencies, which includes areas under that Annex. In detail, detainable deficiencies pursuant to Annex V include: the absence of garbage management plan, garbage record book, and crewmembers' unfamiliarity with requirements for disposing and discharging of garbage in general (IMO, 2021a).

7. The International Safety Management Code (ISM Code)

The SOLAS Convention, Chapter IX – Management for the safe operation of ships requires that shipping companies and their vessels shall comply with the mandatory requirements of the ISM Code (IMO, 1974). With this regard, the Organization underscores the important roles of shipping companies in maritime

safety and security, and the protection of marine environment and the prevention of marine pollution in general, as well as in the prevention of MPP in particular. In fact, the general principles and objectives of the Code demonstrate the recognition from the Organization in terms of the diversity among shipping companies and shipowners, as well as different conditions of their vessels' operations (IMO, 1993; IMO, 2018b). Pursuant to this Code, an international standard is provided for the objectives of ensuring maritime safety, prevention of loss or damage to human life, property, or the marine environment. Particularly important, a shipping company's Safety Management System (SMS) is required to be developed, implemented, and maintained for the effective implementation of, *inter alia*, their safety and environmental policy at all levels of management, either ship-based or shore-based. Through implementation of SMS, mandatory rules and regulations are to be complied, and applicable codes, and recommended guidelines, standards are to be considered. Besides the responsibilities and authorities established for the shipping company (either the operator or the owner), their designated persons, and the masters of their vessels, the Code stipulates specific provisions for shipboard operations, some of which are related to the MPP discussion. In detail, each vessel is required to be appropriately manned with seafarers, who are fit for their respective duties. Especially, proper familiarization is required for either those new personnel or those assigned with new duties, which are in connection with maritime safety and the protection of the marine environment. In addition, the SMS includes established procedures, instructions, plans, and checklists for safe and environmentally sound shipboard operations, as well as programmes for exercises and emergency drills. Critically important, the SMS requires that vessels and their personnel are to report any non-conformities, accidents, and hazardous occurrences to their shipping companies for investigation and analysis, which are followed by corrective actions and the establishment of preventive measures accordingly. The purpose of the report practices is to continuously improve maritime safety and the prevention of pollution.

In general, the Code underscores three main components of the shipping companies' safety management objectives, including, safe and environmentally sound

practices in shipboard operations, risk assessment with the establishment of appropriate safeguards, and continuous improvement. These three factors are required to be committed at all levels of management from shore-based to ship-based personnel. The Code reiterates the importance of these commitments, besides competence, attitudes, and motivations of individual personnel at all levels, with regards to ensuring maritime safety and the prevention of pollution (IMO, 2018b).

8. The International Code for Ships Operating in Polar Waters (Polar Code)

The Organization, through their Polar Code, highlights the distinguished features of the polar waters, e.g., *inter alia*, the remote characteristics, vulnerability, and potentially harsh conditions, which significantly affects maritime safety and the protection of the marine environment (IMO, 2016a). It is important to reaffirm the acknowledgement stated by the Code regarding vulnerability of the coastal communities in the Arctic in particular and the polar ecosystems in general to anthropogenic activities, including shipping-related operations. In fact, the Code is developed on a risk-based approach with the purposes of reducing identified risks, and supplementing existing instruments, of which their mitigation requirements do not adequately address the risks occur in the polar waters, both in terms of safe and environmentally sound operation of vessels, and the protection of the polar environment. Critically important, the Code reiterates the acknowledgement of the Organization regarding the relationship between established safety measures and the protection of the marine environment. This relationship can be explained from the view point of risk assessment in general, and the basic risk equation in particular, which depends on the probability or consequence of the event, or both (IMO, 2018a).

IMO (2016a) reaffirms the purposes to benefit the environment by taking safety measures to reduce the probability of an accident. In contrast, the Organization also underscores those scenarios considered as hazards, when increasing either the probability of occurrence or the severity of consequences, or both; and in the result, their levels of risk will escalate. In detail, those risks are identified and listed under

Paragraph 3 – Sources of hazards. With regards to the MPP discussion in particular and the polar environment in general, some subparagraphs can be considered, i.e., Subparagraphs 6 – 9. These include the potential human error due to crewmembers' experience and the particular polar operations, the difficulties potentially escalating the situations, or affecting the response efforts, or limiting mitigation measures. Concerning the human element in connection with the anthropogenic impacts to the polar environment, Sharlay and Slivaev (2022) highlighted the importance of additional mandatory minimum competence pursuant to the STCW Code, Section A-V/4, especially, in ensuring compliance with pollution-prevention requirements, and preventing environmental hazards.

Particularly important, Subparagraph 10 reiterates the vulnerability of the polar environment, i.e., the areas and their waters are sensitive to harmful substances and other anthropogenic impacts; also, upon affected or damaged, longer time for restoration is required. With regards to the measures for pollution prevention, Part II-A of the Code has five chapters regulating five types or sources of pollution from vessels (similar to certain annexes of the MARPOL Convention, i.e., regarding pollution from oil, noxious liquid substances in bulk, harmful substances carried by sea in packaged form, sewage from ships, and garbage from ships). Within the scope of this Dissertation, Chapter 5 under Part II-A of the Polar Code will be reviewed. Strictly promulgating, all garbage, including all plastics, are prohibited to be discharged into the sea with only some limited exceptions (MARPOL Convention, Annex V, Regulation 3). For instance, cargo residues shall only be discharged when "en route" and satisfying all required conditions, including those regarding the absence of classified harmful substances to the marine environment, requirements of ports of departure and arrival, the unavailability of adequate reception facilities, and a specific value of ice concentration, as well as the minimum distance of 12 nautical miles from the nearest ice shelf, fast ice, or land (IMO, 2016a; Sharlay & Slivaev, 2022).

Finally, the Code also reiterates requirements regarding the placards, the Garbage Management Plan, and the Garbage Record Book pursuant to MARPOL Convention, Annex V, Regulation 10. In other words, every operation in polar waters

shall be taken appropriately into account and recorded accordingly (IMO, 2016a; Sharlay & Slivaev, 2022).

Appendix F

OVERVIEW OF THE REFERENCES

The Dissertation research is primarily based on three methods; namely, systematic literature review, secondary data analysis or archival study, and comparative study. Table S9 summarizes the total quantity of literature used in the Dissertation by category. There are two main types of literature, which are scholarly literature (e.g., articles, reviews, books, and reports), and legal instruments or documents (e.g., conventions, codes, directives, and guidelines). Generally, scholarly literature is selected among high-reputation research papers; whereas, legal instruments and documents are obtained from international institutions in question.

Table S9

Overview of the References

Category	Quantity	(Reference)
SCHOLARLY LITERATURE		
Articles, Reviews	36	
Books	4	
Reports	5	
Assessment	1	(UNEP, 2017)
LEGAL INSTRUMENTS		
Conventions, Protocol	13	
Declaration	1	
Codes	6	

Directives, Resolutions, Circulars, Communication	20
Guidelines, Manual	4
Miscellaneous (Conference paper, Press release, Handbook, Model course, Information booklets, Photographs, Assignments)	18
Total	**108**

[End of the Appendixes.]

[End of the Dissertation.]