
Contents

Part I Introduction

1 Shipping and the Environment	3
Karin Andersson, Francesco Baldi, Selma Brynolf, J. Fredrik Lindgren, Lena Granhag and Erik Svensson	
1.1 Man and the Sea.	4
1.2 Ships and Shipping	6
1.2.1 The Infrastructure: Fairways, Canals and Ports	7
1.2.2 Marine Spatial Planning	7
1.2.3 What Types of Cargo Are Transported by Ships, and Where Is the Cargo Transported?	8
1.3 Sustainability and Shipping	9
1.3.1 Sustainability and Sustainable Development	10
1.3.2 What Is an Environmental Concern?	12
1.3.3 Ecosystem Services	14
1.3.4 Planetary Boundaries	15
1.3.5 Resilience Thinking.	15
1.4 Ships and Their Environmental Impacts	16
1.4.1 A Ship's Life Cycle	18
1.4.2 The Hull and Ship Structure	18
1.4.3 The Propulsion System	19
1.4.4 Hotel Facilities	23
1.4.5 Auxiliary Systems	23
1.5 Sustainability Challenges for the Maritime Industry	24
2 The Natural Environment and Human Impacts	29
J. Fredrik Lindgren, Kent Salo, Selma Brynolf, Karin Andersson, Erik Svensson, Maria Zetterdahl, Lena Granhag and Mathias Magnusson	
2.1 The Hydrosphere	31
2.1.1 Hydrological Cycle—The Water Cycle	32
2.1.2 Chemical and Physical Properties of Water.	32
2.1.3 Oceanography.	37

2.2	The Atmosphere	38
2.2.1	The Structure and the Composition of the Atmosphere.	38
2.2.2	Radiation and Energy Budgets	40
2.2.3	Weather and Climate	42
2.3	The Geosphere	43
2.4	The Biosphere	45
2.4.1	Primary Production and Food Chains.	45
2.4.2	Living in Sea Water—Implications for Marine Organisms	46
2.5	Biogeochemical Cycles	48
2.5.1	The Sulphur Cycle	48
2.5.2	The Nitrogen Cycle.	49
2.5.3	The Carbon Cycle.	50
2.6	Energy Sources.	51
2.6.1	Fossil Energy Sources	51
2.6.2	Renewable Energy Sources.	56
2.7	Human Impacts and Environmental Issues	57
2.7.1	Stratospheric Ozone Depletion	59
2.7.2	Loss of Biodiversity	59
2.7.3	Chemical Pollution and the Release of Novel Entities.	60
2.7.4	Climate Change	64
2.7.5	Ocean Acidification.	66
2.7.6	Freshwater Consumption and the Global Hydrological Cycle	67
2.7.7	Land System Change.	67
2.7.8	Alteration of Biogeochemical Flows	67
2.7.9	Air Pollution	69
2.8	Summary	71
	References.	71
3	Regulating Pollution from Ships	75
	Philip Linné and Erik Svensson	
3.1	A Short History of the Regulation of Ship Operations	77
3.2	The History of the Regulation of Pollution from Ships	78
3.3	The Legal Framework for Regulating Pollution from Ships	82
3.3.1	An Introduction to the International Law Context	82
3.3.2	An Introduction to the Law of the Sea Context.	84
3.3.3	Links Between the LOSC and the Role of IMO in the Regulation of Pollution from Ships.	91
3.3.4	An Introduction to MARPOL 73/78 and its Annexes	94
3.3.5	Other International Agreements Regulating Pollution from Ships	96

3.4	The Role of IMO in the Regulation of Pollution from Ships. . .	101
3.4.1	Functions and Structure	101
3.4.2	An Overview of Actors at IMO	105
3.5	An Introduction to the Crafting of International Agreements. . .	110
3.5.1	Basic International Agreement Terminology	112
3.5.2	The Crafting of IMO Conventions on Pollution from Ships	114
	References.	118

Part II Environmental Impacts

4	Discharges to the Sea	125
	J. Fredrik Lindgren, Magda Wilewska-Bien, Lena Granhag, Karin Andersson and K. Martin Eriksson	
4.1	Oil	127
4.1.1	Discharges of Oil from Shipping.	129
4.1.2	Behaviour of Oil Spills	135
4.1.3	Impacts of Oil	137
4.1.4	Costs Related to Petroleum Contamination	139
4.2	Wastewater	141
4.2.1	Origin and Characteristics of the Wastewater Streams	141
4.2.2	Environmental Effects	142
4.2.3	Regulations	143
4.3	Fouling, Ship Hull Penalties and Antifouling Paint	145
4.3.1	Antifouling Paints	150
4.3.2	Non-metal-Based Booster Biocides	151
4.3.3	Metal-Based Booster Biocides	153
4.3.4	Regulations	153
4.4	Ballast Water	153
4.4.1	Background and History	153
4.4.2	Ecosystem Impacts	155
4.4.3	Estimated Costs and Societal Impacts	156
4.4.4	Human Health Impacts	156
4.4.5	Regulations	156
4.4.6	Ballast Water Exchange	157
4.5	Marine Litter	157
4.5.1	Impacts of Marine Litter	159
4.5.2	Economic Consequences	160
4.5.3	Regulations	161
	References.	162

5	Emissions to the Air	169
	Kent Salo, Maria Zetterdahl, Hannes Johnson, Erik Svensson, Mathias Magnusson, Cecilia Gabriellii and Selma Brynolf	
5.1	Marine Diesel Engines and Emission Formation	174
5.1.1	Marine Diesel Engines	174
5.1.2	Combustion Process in Diesel Engines	176
5.1.3	Thermochemistry Related to Combustion in Diesel Engines	177
5.2	Greenhouse Gases (GHGs)	178
5.2.1	Sources	180
5.2.2	Human and Environmental Implications	181
5.2.3	Regulations	182
5.3	Sulphur Oxides	186
5.3.1	Sources	187
5.3.2	Transboundary Impacts	188
5.3.3	Regulations	190
5.4	Nitrogen Oxides	192
5.4.1	Formation	193
5.4.2	Human and Environmental Implications	196
5.4.3	Regulations	197
5.5	Particles	202
5.5.1	Formation	203
5.5.2	Human and Environmental Implications	208
5.5.3	Regulation	210
5.6	Volatile Organic Compounds	211
5.6.1	Sources	212
5.6.2	Human and Environmental Implications	212
5.6.3	Regulations	213
5.7	Ozone-Depleting Substances (ODS)—Refrigerants	213
5.7.1	Sources	214
5.7.2	Human and Environmental Implications	215
5.7.3	Regulations	217
	References	218
6	Anthropogenic Noise	229
	J. Fredrik Lindgren and Magda Wilewska-Bien	
6.1	Noise	230
6.1.1	Underwater Noise	230
6.1.2	Noise from Port Areas	232
	References	234
7	Infrastructure, Marine Spatial Planning and Shipwrecks	237
	J. Fredrik Lindgren, Karin Andersson and Hanna Landquist	
7.1	Ports	238
7.2	Fairways and Canals	240

7.3	Dredging	241
7.4	Ship Construction and Scrapping	242
7.4.1	Design Phase	243
7.4.2	Manufacturing Phase and Shipyards	244
7.4.3	Operational Phase	245
7.4.4	Scrapping of Ships	245
7.4.5	Regulations	248
7.5	Shipwrecks.	249
7.5.1	Regulations	250
7.6	Marine Spatial Planning.	250
7.6.1	Regulations	251
	References.	252

Part III Pollution Prevention Measures

8	Environmental Management	257
	Karin Andersson	
8.1	What Is Environmental Management?	258
8.2	Strategies in Environmental Management.	258
8.3	Environmental Management Systems and Standards	260
8.4	Environmental Reporting and the Global Reporting Initiative (GRI).	262
	References.	263
9	Methods and Tools for Environmental Assessment.	265
	Karin Andersson, Selma Brynolf, Hanna Landquist and Erik Svensson	
9.1	Principles of Systems Analysis	267
9.2	Environmental Systems Analysis.	268
9.3	Procedural Tools.	269
9.3.1	Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA)	269
9.3.2	Scenario Analysis	272
9.3.3	Multi-Criteria Decision Analysis (MCDA)	273
9.3.4	Risk Management	275
9.4	Analytical Tools	276
9.4.1	Life Cycle Assessment (LCA)	276
9.4.2	Material Flow Analysis (MFA) and Substance Flow Analysis (SFA).	279
9.4.3	Environmental Risk Assessment (ERA)	280
9.4.4	Cost-Benefit Analysis (CBA)	281
9.4.5	Life Cycle Costing (LCC)	282

9.5	Aggregated Tools	283
9.5.1	Indicators	283
9.5.2	Indices	284
9.5.3	Footprints	287
	References	290
10	Energy Efficiency and Fuel Changes to Reduce Environmental Impacts	295
	Selma Brynolf, Francesco Baldi and Hannes Johnson	
10.1	Energy Efficiency Potential and the Energy Efficiency Gap . . .	297
10.2	Improving Energy Efficiency from a Design Perspective	299
10.2.1	Reducing Ship Energy Requirements	300
10.2.2	Improving the Energy Efficiency of Converters and Transmitters	303
10.2.3	Using Additional Renewable Energy Sources	310
10.3	Improving Energy Efficiency from an Operational Perspective	313
10.3.1	The Assessed Potential	313
10.3.2	The Role of Ship Speed	314
10.3.3	Improved Energy-Management Practices	315
10.4	Fuel Changes to Reduce Environmental Impacts	318
10.4.1	Criteria for Future Marine Fuels	319
10.4.2	Present and Possible Future Marine Fuels	323
10.4.3	Life Cycle Assessment of Marine Fuels	331
	References	334
11	Measures to Reduce Discharges and Emissions	341
	Magda Wilewska-Bien, J. Fredrik Lindgren, Mathias Magnusson, Maria Zetterdahl, Kent Salo, Cecilia Gabrielii, Lena Granhag and Selma Brynolf	
11.1	Remediation of Oil Spills	342
11.1.1	Techniques Used at Sea	343
11.1.2	Techniques Used on Shores	345
11.1.3	Treatment of Bilge Water	346
11.2	Antifouling	347
11.2.1	Non-toxic Antifouling Technologies	347
11.2.2	Areas of Research	348
11.3	Ballast Water	349
11.3.1	Mechanical and Physical Treatments	349
11.3.2	Treatment Methods Using Chemicals	350
11.3.3	Other Alternatives	351
11.4	Wastewater	351
11.5	Solid Waste	355
11.6	Greenhouse Gases (GHGs)	357

11.7	Nitrogen Oxides	358
11.7.1	Selective Catalytic Reduction (SCR)	359
11.7.2	Alternative Fuels.	365
11.7.3	Basic and Advanced Internal Engine Modification (IEM)	365
11.7.4	Addition of Water to the Combustion Process.	367
11.7.5	Exhaust Gas Recirculation (EGR)	369
11.7.6	IMO Tier III Compliance Using Combined NO _x -Abatement Technologies.	370
11.8	Sulphur Oxides.	371
11.8.1	Low-Sulphur Fuels	371
11.8.2	Scrubbers.	372
11.9	Non-methane Volatile Organic Compounds	379
11.10	Particles.	379
11.11	Ozone-Depleting Substances (ODS).	382
11.11.1	Minimising Leakage	382
11.11.2	Refrigerants with Zero ODP.	382
11.12	Measures to Reduce Noise	383
11.13	Reducing the Impacts from Shipping Infrastructure	384
11.13.1	Measures Related to Ports	384
11.13.2	Measures Related to Canals and Fairways	385
11.13.3	Measures Related to Dredging	386
11.13.4	Measures Related to Shipbuilding and Scrapping	386
11.14	Shipwreck Remediation	386
11.15	Actions to Implement a Marine Spatial Plan.	387
	References.	388

Part IV Outlook

12	Improving Environmental Performance in Shipping	399
	Selma Brynolf, J. Fredrik Lindgren, Karin Andersson, Magda Wilewska-Bien, Francesco Baldi, Lena Granhag, Hannes Johnson, Philip Linné, Erik Svensson and Maria Zetterdahl	
12.1	Policy Goals and Consumer Demands	401
12.2	The Current Situation and Future Challenges	402
12.2.1	Discharges to the Sea	402
12.2.2	Emissions to the Air	404
12.2.3	Noise.	407
12.2.4	The Arctic	408
12.3	Pathways to Obtain Environmentally Sustainable Shipping	409
12.3.1	Environmental Awareness	409
12.3.2	Regulations and Enforcement	410
12.3.3	Technical Solutions	412
12.4	Final Remarks	416
	References.	417
	Index	419