Swedish Institute for the Marine Environment

Demand and supply by Erik Johansson

MITIGATING MARINE EUTROPHICATION IN THE PRESENCE OF STRONG SOCIETAL DRIVING FORCES

SWEDISH INSTITUTE FOR THE MARINE ENVIRONMENT

REPORT NO. 2017:3

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The Swedish Institute for the Marine Environment is a collaboration between five universities: Umeå University, Stockholm University, Linnaeus University, the Swedish University of Agricultural Sciences and University of Gothenburg.

Report No. 2017:3

Release date: 2017-05-10

Title: Mitigating marine eutrophication in the presence of strong societal driving forces

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Please refer to this report as:
Grimvall, A., Sundblad, E-L., Sonesten, L. (2017) Mitigating marine eutrophication in the presence of strong societal driving forces. Report No. 2017:3. Swedish Institute for the Marine Environment

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PREFACE

This report, which was commissioned and financed by the Swedish Agency for Marine and Water Management (SwAM), is devoted to current and potential future measures to mitigate the eutrophication of marine waters. It is meant to be used as a background report for Swedish actors at the high-level UN Ocean Conference that will convene at the UN Headquarters in New York in June 2017. This Conference aims to support the implementation of Sustainable Development Goal 14: ´Conserve and sustainably use the oceans, seas and marine resources for sustainable development´ and is intended to be the game changer that will reverse the decline in the health of our oceans for the benefit of people, the planet, and prosperity.

This report also aims to serve as a motivator for further actions against marine eutrophication in both Sweden and in other countries, and it brings together both old and new perspectives on measures that can prevent and reduce marine eutrophication. A review of current measures in selected countries is complemented by a presentation of potential new measures that can expand the range of intervention options. Special attention is paid to transformative measures that involve new groups of actors and that take into account relevant societal trends. A set of recommendations for decision-makers in governments, agencies, and commercial enterprises concludes the report.

The authors are grateful for constructive discussions with Ulrika Siira, Emmelie Johansson, Philip Axe, and Robert Almstrand (SwAM), Magnus Bång (Swedish Board of Agriculture), Rudolf Hermes (Bay of Bengal project BOBLME), Prosun Bhattacharya (Royal Institute of Technology, KTH), Susanne Lindegarth (University of Gothenburg), Anders Alm (World Wildlife Foundation, WWF), Christoph Humborg, Michelle McCrackin, Annika Svanbäck, and Gun Rudquist (Stockholm University Baltic Sea Centre), Jacob Carstensen, and Lars Svendsen (Aarhus University), and Douglas Lipton (National Oceanographic and Atmospheric Administration, NOAA). We are also grateful for the comments from a number of anonymous reviewers as well as from colleagues. However, the authors are solely responsible for the content and the conclusions of the report.

ANDERS GRIMVALL, EVA-LOTTA SUNDBLAD, AND LARS SONESTEN

GOTHENBURG, 10 MAY 2017

EXECUTIVE SUMMARY

Man-made eutrophication of lakes, coastal waters, and oceans occurs in practically all populated parts of the world, and in many regions the problem is increasing. The ecological effects of excessive input of nutrients include massive algal blooms, extensive oxygen depletion, and recurrent incidences of fish kills. The East China Sea, the Gulf of Mexico, the Bay of Bengal, and the Baltic Sea are some examples of sea basins in which nutrient over-enrichment has resulted in unnaturally large hypoxic zones, where the oxygen concentration is so low that animal life suffocates and dies. Such serious effects are negative not only for ecological reasons, but they also mean the loss of economically valuable resources.

Measures to prevent or reduce fluxes of nutrients into marine waters were first undertaken in some parts of Europe and North America. Wastewater treatment plants in urban areas were upgraded to enable the efficient removal of nutrients, and discharges from industry were substantially reduced. Step by step, diffuse emissions from agriculture, transport, and other sectors were also addressed. A brief review of the measures currently in place in a number of countries showed that, despite progress in some areas, the targets of international conventions and other agreements are rarely completely achieved. One reason might be that the flow of nutrients through society and into coastal waters is strongly intertwined with basic human needs, especially the production and consumption of food. Another reason might be that all relevant actors do not participate in the mitigation efforts. In addition, the impact of global social and economic trends is rarely addressed by the authorities who are developing programs of measures (POMs).

This report elucidates how politicians, numerous decision-makers in both authorities and enterprises, and conscious consumers can help to reduce eutrophication of coastal waters and oceans. This is done by first reviewing the current measures and instruments in place to mitigate marine eutrophication. Thereafter, it is explored how the range of intervention options can be expanded by systematically linking the flows of substances and goods to the relevant actors and by assessing these actors' potential to influence nutrient fluxes. Selected global trends and innovative technologies of relevance are also considered. Moreover, the need and benefit of simultaneously working toward different sustainable development goals is addressed.

Current measures in selected countries.
Sweden, which is one of the nine Baltic Sea countries, has developed a very complex mix of physical measures and policy instruments to combat marine eutrophication. Efficient wastewater treatment has been accomplished by simultaneously paying attention to institutions, legislation, and financing of measures. Leakage of nutrients from agriculture has been reduced by combining legislation and ordinances from the Government and national agencies with inspections and guidance from county administrative boards and municipalities. Voluntary actions by farmers are to some extent subsidized. Emissions from shipping, especially nitrogen emissions from fuel combustion, are another major source of marine eutrophication, and national regulations have been decided upon and implemented. Collaboration with other countries is needed to achieve unified actions, but such actions take time.

Denmark, which is another Baltic Sea nation, produces large amounts of pig meat, and this has made it necessary to address the leakage of nutrients from agriculture. Originally, nitrate pollution of inland waters and groundwater was in focus, but measures to protect such waters have also resulted in the improved status of marine waters. Politically, Denmark has met the challenges by employing two different abatement strategies. Detailed regulation of agricultural practices using almost identical rules in the whole of Denmark is now being replaced by spatially differentiated regulation.

The Netherlands by the North Sea is another country with large-scale and intensive animal farming. Because livestock production generates considerably more manure than is required by agriculture in the immediate vicinity, the cycling of nutrients is disrupted. To reduce regional imbalances in nutrient fluxes, Dutch farmers are now required to have a certain percentage of their surplus manure treated for sale outside the Dutch fertilizer market.

In the US, POMs have long had a strong focus on point-source emissions, including emissions from concentrated animal feeding operations. Extensive outreach activities, voluntary actions, and strong ambitions to involve a wide range of stakeholders characterize several of the POMs. However, the overall progress to reduce fundamental imbalances in nutrient fluxes in food production has been slow.

India and Bangladesh, which border the Bay of Bengal, are two countries with a rapidly increasing population and rapid urbanization. Urban sanitation and wastewater treatment for the large cities are in focus, but without upgrading the treatment systems so that they include efficient removal of nutrients, there is a substantial risk of increased eutrophication problems.

China has changed faster than any other large country over the past few decades. New environmental laws and substantial investments in wastewater treatment plants indicate an increased willingness to address water pollution, including marine eutrophication. However, implementation of new environmental standards is lagging behind changes in nutrient fluxes. The impact of urbanization, transitions in agriculture, and dietary shifts are so strong that fundamental imbalances in nutrient fluxes are likely to persist for a long time.

Generally, abatement of eutrophication problems starts with efforts to eliminate hot spots of nutrient pollution by regulating point-source emissions and agricultural practices. Addressing eutrophication by considering large-scale imbalances in nutrient fluxes and desirable transitions in society usually comes later. Increased cooperation within sea conventions, stronger involvement of major enterprises, and coordinated efforts to simultaneously achieve several sustainable development goals represent a way forward.

Cooperation within international sea conventions and watershed task forces

In Europe, the contracting partners of the HELCOM and OSPAR conventions are cooperating to reduce eutrophication in the Baltic Sea and the Northeast Atlantic, respectively. Such regional sea conventions are important platforms for mutual decisions between the member states. They also form bodies large enough to push forward issues in global organizations such as the International Maritime Organization. The European Union broadens the cooperation possibilities by offering more partners and by providing unified legislation and financial support.

India and Bangladesh participated in the Bay of Bengal Large Marine Ecosystem project as a way to share visions and objectives and to engage in discussion concerning the measures to be implemented. This project ended in 2015, and future work related to the project is currently being discussed.

In the US and China, the Mississippi and Yangtze river basins are so large that watershed task forces play a key role in abatement programs.

Expansion of intervention options

The human pressure on many coastal and offshore water bodies remains unacceptably high even though several measures have already been implemented. This indicates that there is a need to expand the range of intervention options. Systems analysis of fluxes of nutrients through society can reveal a multitude of activities and behavioral patterns of institutions, organizations, and individuals that affect the pressure on marine environments.

When developing policy instruments and measures to reduce the pressure on marine environments, it is important to identify actors who have the potential to change their behaviors. By analyzing product chains, it is often possible to identify such actors or groups of actors. A case study of the product chain for meat produced and consumed in Sweden revealed that although the number of activities in the chain is large, the actual number of influential actors is rather small. This study also showed that it is not only the actors who actually release nutrients into the sea who can influence the nutrient loads. Large food retailers, for example, can influence what is consumed and thereby also the fluxes of nutrients along the entire chain from production of animal feed and food to emissions from sewage systems. Chefs with a media presence, NGOs, and conscious consumers are other examples of key actors.

Taking stock of the current measures as well as our general procedure for linking key actors to fluxes of substances and products, we propose new measures to mitigate the eutrophication of marine waters. In contrast to many of the current measures that can be characterized as end-of-pipe solutions or cleanup operations, these new measures have the potential to transform society into becoming more ecologically, economically, and socially sustainable. The proposed measures all relate to dietary issues or to better recycling of nutrients.

Three proposed measures

A. Protein consumption adjusted to health requirements.

People in many countries have increased their average protein consumption to levels far higher than needed. Phosphorus and nitrogen fluxes through society and from society to nature increase with increased protein consumption. Taking Sweden as an example, a 20% lower production and consumption of protein could substantially lower the nutrient input into the Baltic Sea without increasing the risk of protein deficiency. Such dietary changes are in the hands of many actors such as legislators, agencies, market actors, and NGOs.

B. Increased aquaculture with minimal loss of nutrients.

Aquaculture has considerable potential to efficiently produce high-quality protein. Fish farming in land-based recirculating systems allows almost full control of nutrient fluxes. Using feed that is not based on marine animals, the pressure on the marine environment is also minimized in other respects. Market actors and entrepreneurs can support this development, but government involvement is needed for guidance, monitoring, and regulation. In addition, consumers need guidance and motivation to change their eating habits.

C. Recovery of phosphorus from sewage sludge.

Wastewater treatment plants produce increasing amounts of sludge that contains valuable nutrients, especially phosphorus. However, due to undesirable pollutants, the use of sludge for direct application on arable land is limited in many countries. Due to the worldwide urbanization trend, there is also an increasing need to recirculate nutrients from cities to arable land. With new technologies, and at reasonable cost, phosphorus can be recovered from sludge as a clean product that can be traded. Politicians can contribute to this development by creating proper legislation and by stimulating cities to become models for nutrient recycling.

Ten recommendations

The report contains a set of recommendations that can help to achieve the UN sustainable development goal about life below water (SDG 14) by pushing forward transformative changes in society.

First, promote activities that raise awareness of the root causes of eutrophication! The awareness of how societal trends and the behavior of numerous actors in society contribute to pressure on marine environments is insufficient. National agencies and actors in the food sector can:

1. Establish recognized platforms where professional actors from national agencies, local authorities, and the food sector are invited to identify their own role and their own responsibility for reducing eutrophication.
2. Develop tools and platforms that can facilitate collaboration between actors in different parts of a product chain with a common goal to reduce marine eutrophication.

Moreover, engage commercial actors to promote sustainable diets! Many consumers have an overconsumption of protein, especially red meat. Governments, national agencies, and commercial actors in the food sect can:

3. Take actions to make it easier for consumers to adjust their total intake of protein to levels motivated by health reasons.

Support new concepts for more efficient recycling of plants nutrients! Urbanization and industrialization of agriculture have created fundamental regional imbalances in the fluxes of nitrogen and phosphorus. Governments can:

4. Implement mandatory processing and recycling of surplus manure in regions with intensive animal farming and support innovations in the processing of manure into valuable, transportable products.
5. Introduce mandatory recovery of depolluted phosphorus from sewage sludge and develop an internationally harmonized quality control framework for recycling of phosphorus into agricultural soils.

Support sustainable forms of aquaculture! Fish farming in land-based recirculating systems along with limited use of animal feed can offer more sustainable nutrient fluxes. Non-fed aquacultures of mollusks and seaweeds are underexploited sources of food in large parts of the world. Governments and politicians can:

6. Support the development of environmentally sound systems for fish production in land-based closed containments and establish or support a certification system for such production.
7. Promote expansion of markets for mollusks and seaweeds from non-fed aquacultures.

Establish strong institutions with a mandate to undertake coordinated actions! Governments can:

8. Use regional sea conventions and watershed programs to promote cleanup operations as well as transformative measures regarding food production and consumption.
9. Give national authorities the mandate to handle goal conflicts so that mitigation of marine eutrophication is accomplished without sacrificing food security or other sustainable development goals.

Finally, capitalize on environmental synergies! Governments and national agencies can:

10. Make efficient use of climate actions that also mitigate eutrophication effects.

LIST OF ACRONYMS

BoB	Bay of Bengal
BOBLME	Bay of Bengal Large Marine Ecosystem Project
BONUS	A joint Baltic Sea research and development program
BSAP	Baltic Sea Action Plan
CAB	County Administrative Board, here referring to Sweden
CAFO	Concentrated Animal Feeding Operations
CBW	Chesapeake Bay Watershed
CPCB	Central Pollution Control Board, here referring to India
EPA	U.S. Environmental Protection Agency
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GEF	Global Environment Facility
GES	Good Environmental Status
HELCOM	Baltic Marine Environment Protection Commission – Helsinki Commission
IMO	International Maritime Organization
MSFD	EU Marine Strategy Framework Directive
N	Nitrogen
NECA	Nitrogen Emission Control Area
NEFCO	Nordic Environment Finance Corporation
NGO	Non-governmental organization
NOAA	U.S. National Oceanic and Atmospheric Administration
NOx	Nitrogen oxides
NPDES	National Discharge Elimination System, here referring to US
OECD	The Organization for Economic Co-operation and Development
OSPAR	The Convention for the Protection of the Marine Environment of the North-East Atlantic
POM	Program of measures to achieve a specific goal
QSR 2021	OSPAR Quality Status Report for 2021
RAS	Recirculating Aquaculture Systems

RBDA	River Basin District Authority, here referring to Sweden
RSC	Regional Sea Convention
SBoA	Swedish Board of Agriculture
SDG	UN Sustainable Development Goal
SIDA	Swedish International Development Cooperation Agency
SRDP	Swedish Rural Development Program
STA	Swedish Transport Agency
SwAM	Swedish Agency for Marine and Water Management
TMDL	Total Maximum Daily Load
UNEP	United Nations Environment Program
WFD	EU Water Framework Directive

CONTENTS

1 INTRODUCTION

Man-made eutrophication of lakes, coastal waters, and oceans occurs in practically all populated parts of the world. The ecological effects of excessive input of nutrients include massive algal blooms, extensive oxygen depletion, and recurrent incidences of fish kills. The map in figure 1 shows a compilation of scientifically documented dead zones in the world's oceans, and especially their coastal waters. In all of these zones, the oxygen concentration can be so low that animal life suffocates and dies. Consequently, it is logical that nutrient pollution of marine waters is one of the environmental problems that are addressed in the UN Sustainable Development Goal regarding life below water (SDG 14). According to Target 14.1 of this goal, marine pollution of all kinds, including marine debris and nutrient pollution, shall be prevented and significantly reduced by 2025. Moreover, special attention shall be paid to pollution from land-based activities.

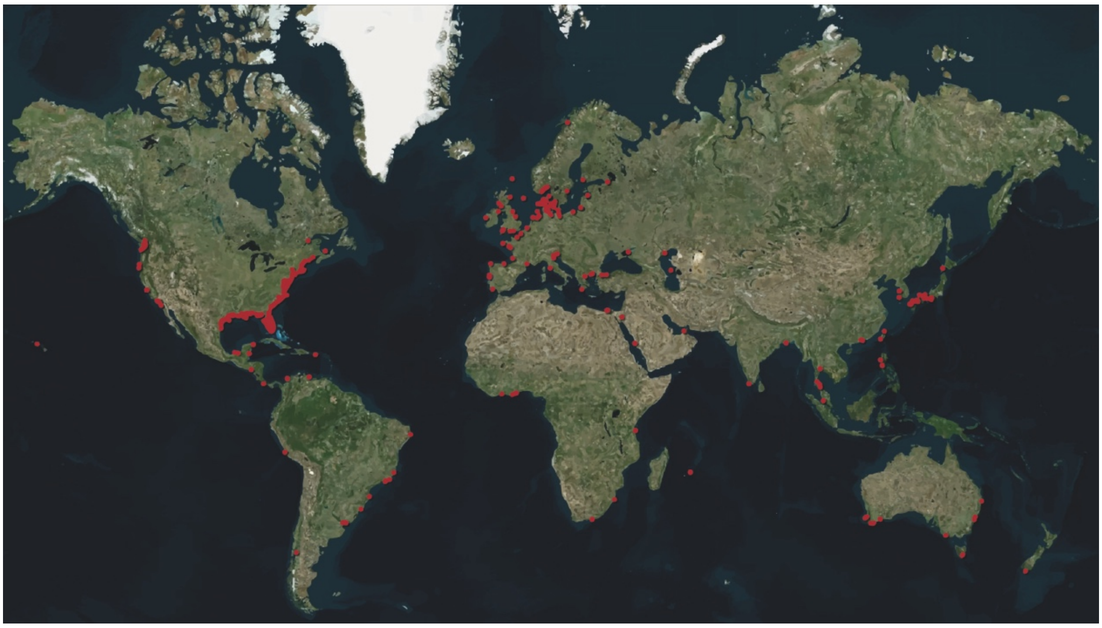

Figure 1. Scientifically documented hypoxic zones in the world's coastal waters since 1980. Source: World Resources Institute[1]. Red dot = hypoxic zone.

Compared to the large number of assessments of the ecological and chemical state of marine environments, there are few evaluations of the measures taken to reduce the fluxes of nitrogen and phosphorus into the sea. It is even difficult to overview which general policy instruments and specific measures are being used and to what extent they are implemented. Moreover, it is difficult to separate the effects of measures designed to mitigate eutrophication from weather-driven random fluctuations and the effects of general trends and driving forces in society. Due to this lack of information, there is an urgent need to review measures currently in place. In addition, new measures need to be explored to further support mitigation activities against eutrophication.

This report aims to elucidate how a great variety of actors in society, including decision-makers in agencies and enterprises, can help to reduce unwanted eutrophication of coastal waters and oceans. More specifically, the report aims to:

- Review current measures and instruments to mitigate marine eutrophication in selected sea areas
- Explore how the range of intervention options to reduce the influx of nutrients into marine waters can be expanded
- Draw attention to some global trends and innovative technologies that complicate or facilitate mitigation of eutrophication
- Draw attention to the need for coordinating actions to simultaneously achieve different sustainable development goals

The difficulties in mitigating eutrophication are strongly related to the fact that the flow of nutrients through society and into coastal waters is intertwined with basic human needs, especially the production and consumption of food. Moreover, global driving forces are interlinked with national aspirations and local initiatives. This implies that the eutrophication of marine environments can be influenced by a much larger group of individuals and organizations than those normally involved in the development and implementation of measures to reduce nutrient fluxes into the sea. As a consequence, effective mitigation of eutrophication can require a complex mix of international regulations and conventions, national standards and economic incentives, local measures, and voluntary initiatives.

When man-made eutrophication of water bodies in the late 1960s became a major environmental issue in Europe and North America, ecological changes in freshwater systems were in focus. Scientific evidence was accumulating showing that increased influx of phosphorus into lakes and rivers was a key factor[2,3], and more efficient removal of this element in wastewater received a high priority in the first abatement programs[4].

Eutrophication of large coastal waters or the open sea was almost unheard of as late as 1970, and it was not until the late 1980s that this issue appeared high on the political agenda[5,6]. With the greater attention to marine environments, there was also greater emphasis on the role of nitrogen in the eutrophication of aquatic environments[7]. In addition, the crucial role of diffuse sources, especially emissions from agriculture and combustion of fossil fuels, including transport[8,9], was more generally recognized.

Over the past decade, it has become increasingly obvious that eutrophication of marine waters is a global phenomenon[10,11,12]. The previously cited survey carried out by the World Resources Institute (see figure 1) revealed 530 sites experiencing oxygen depletion. Quantitative estimates of natural and anthropogenic flows of nitrogen and phosphorus have provided additional evidence of the extensiveness of human impact. Production of commercial fertilizers and combustion of fossil fuels now convert more nitrogen gas from the atmosphere into reactive forms than all natural processes in terrestrial ecosystems[13], and model calculations indicate that the nitrogen loads into coastal waters have more than doubled since 1850[14]. The flow of phosphorus through society and nature has also undergone dramatic changes, and the fluxes into coastal waters have almost doubled since 1850[14]. The consequences of this global interference with the natural nitrogen and phosphorus cycles are still a matter of discussion. However, it has been argued that human activities now might exceed long-term planetary boundaries by eroding the resilience of important marine systems[15].

Scale issues also play a key role in the development of programs of measures (POMs) to reduce undesirable eutrophication effects. Marine eutrophication might have hot spots caused by a single source, but the mere size of many of the affected sea areas calls for cooperation across national borders and sectors in society. Today, more than 143 countries have joined 18 Regional Seas Conventions and Action Plans for the sustainable management and use of the marine and coastal environment[16]. In Europe, for example, much of this cooperation takes place within the Regional Seas Conventions regarding the Baltic Sea and the Northeast Atlantic[17,18] and through the implementation of a series of EU directives.

In large countries, it can be a challenge to coordinate measures in different states or provinces. In the United States, for example, the authority for point source control is allocated to federal authorities, whereas individual states have the main responsibility for non-point source control[19]. In China, the national government sets national environmental quality and technology standards, but leaves most of the practical measures to preventing aquatic pollution to provincial or local authorities.

The success of mitigation efforts varies between sea areas[20,21,22,23]. International conventions and major national programs can have positive effects by (i) defining clear goals, (ii) creating data and knowledge centers, and (iii) offering possibilities to find cost-effective solutions. However, a quick review of current POMs also reveals some general weaknesses:

- The targets of international conventions and other agreements are rarely completely achieved.
- All relevant sectors or actors in society do not participate in the mitigation efforts.
- The impact of global, social, and economic trends is rarely addressed.

This report takes Swedish marine waters and efforts to reduce the eutrophication of the Baltic Sea as the point of departure for a review of current measures. The scope of the synthesis is then extended to other nations and regions. The Gulf of Mexico, The East China Sea, and the Bay of Bengal were selected because these sea areas appear on a list of marine ecosystems at high risk according to the Transboundary Waters Assessment Programme[24]. The Chesapeake Bay and the Baltic Sea were included because these waters played a crucial role in putting marine eutrophication on the political agenda. Physical measures and instruments in specific nations are mentioned when they exemplify measures of particular interest.

The review of current measures acknowledges progress that has been made to reduce emissions from sewage systems and agriculture. However, it also pays attention to additional measures that could become important complements to existing measures. Some of the new intervention options presented here emphasize the role of market actors and consumers. Moreover, it is argued that systems analysis of the flow of products through society and the systematic identification of relevant actors can play a key role in expanding the range of intervention options.

Throughout the report, it is argued that POMs must take into account relevant global trends. The following four trends are considered to be particularly important: (i) the increasing total and per capita intake of protein and energy[25], (ii) the disconnection of crop production and animal feeding operations[26,27], (iii) the rapid urbanization[28], and (iv) the increasing global shipping[29]. In addition, it is shown how aquacultures in closed containments or non-fed systems can contribute to more sustainable diets, and how the recovery of phosphorus from sewage sludge can contribute to circulate a valuable resource.

The last sections of the report are devoted to recommendations for more efficient mitigation of marine eutrophication. In particular, it will be argued that sustainable development of nitrogen and phosphorus cycles requires both sustainable production and sustainable consumption[30,31] and that measures to reduce eutrophication of marine environments need to be coordinated with climate actions.

2 THE BALTIC SEA

The Baltic Sea is enclosed by Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Poland, Germany, and Denmark (figure 2), and about 90 million people live in its catchment area. Freshwater runoff from surrounding land areas creates sea basins with a salinity much lower than that of ocean water – the lowest levels are in the north, and the highest are near the outlet through the Kattegat. Long residence time (30–50 years) of the water in the Baltic Sea makes it susceptible to pollution. The water exchange is further constrained by a vertical salinity stratification of the major basin, the Baltic Proper. The area of the hypoxic zone in this basin has grown to approximately 60,000 km^2 in recent years[1].

Figure 2. Map of the Baltic Sea and the countries enclosing this sea. Source: www.d-maps.com (see References).

In the Baltic Sea, eutrophication is one of the main environmental problems, and it is caused by excessive inputs of nutrients over long periods of time. In this chapter, measures to mitigate eutrophication are reviewed for the two countries of Sweden and Denmark. The review of measures in Sweden illustrates how a complex weave of policy instruments and physical measures has been built up over several decades. Measures in Denmark were reviewed because this country has a highly-developed agriculture sector, including a huge livestock production. It is also of interest to note that a system originally based on mandatory regulations for the whole of Denmark is now being replaced by spatially differentiated regulations. In the last part of this chapter, the measures related to the European Union (EU) directives and HELCOM are briefly reviewed.

2.1 MEASURES IN SWEDEN

2.1.1 ENVIRONMENTAL AWARENESS, LEGISLATION, AND INSTITUTIONS

The modern Swedish history of water pollution management illustrates how the formulation and delineation of pollution problems can change over time and how this can influence the choice of solutions. Until the early 1950s, dilution of sewage and industrial wastewaters in sufficiently large recipients was the dominating management strategy. Then a growing awareness of sanitary and hygienic problems pushed through a paradigm shift – wastewater should be purified before it is released into aquatic environments[2]. Mechanical treatment of wastewater was stipulated by law in 1957, but nutrient removal was not efficiently enforced. The Water Inspectorate that was supposed to supervise industrial pollution and examine all plans for sewage treatment was a tiny agency. Moreover, economic growth and improved sanitary and hygienic conditions had a higher priority than the recreational values of aquatic environments threatened by over-enrichment of nutrients.

In the 1960s, the awareness of environmental pollution problems grew stronger. Swedish national policies regarding water and land use were developed, and more attention was paid to institutions, legislation, and financing of measures. The Swedish Environmental Protection Agency was formed in 1967. Two years later, a new Environmental Protection Act with a general ban on releasing untreated wastewater came into force. Moreover, nutrient pollution appeared higher on the political agenda, and state subsidies for improved wastewater treatment were directed to the construction of tertiary treatment plants.

2.1.2 HEAVY INVESTMENTS IN TERTIARY TREATMENT OF URBAN WASTEWATER

When eutrophication of inland waters had been recognized as a major environmental issue and a legitimate actor had been established, measures were promptly implemented. Already in the mid-1970s, the emissions of phosphorus and biodegradable organic matter from wastewater treatment plants had been reduced to the level of the 1940s[2,3]. However, the way forward after these heavy investments was far from clear. It was not until massive algal blooms and fish kills were observed in coastal waters that nutrient emissions into marine environments became an issue, and as late as the mid-1980s it was still advocated that long enough distribution pipes and sufficient water turnover in receiving waters could reduce the negative effects of wastewater emissions to an acceptable level. It took yet another decade until investments in improved nitrogen removal peaked.

The current removal rate of phosphorus and biodegradable organic matter is around 95% in all major municipal wastewater treatment plants. The removal of nitrogen is less efficient (on average 60%), and the highest removal rates have been established in plants emitting into nitrogen vulnerable recipients.

The sludge produced in wastewater treatment plants contains valuable nutrients, especially phosphorus. In principle, it would be desirable to recirculate these nutrients into food production. However, sewage sludge also contains heavy metals, toxic organic pollutants, and drug residues that prevent large-scale application of sewage sludge onto agricultural soils. The current strategies to close this gap in the nutrient fluxes involve three types of measures: (i) campaigns to reduce disposal of harmful substances into flush toilets, (ii) development of processes to degrade drug residues in the treatment plants, and (iii) development of a certification system (REVAQ[4]) for active upstream work and recycling of nutrients in the sludge.

2.1.3 GREATER ATTENTION TO SMALL SEWAGE SYSTEMS

Many rural permanent and holiday homes in Sweden are not connected to municipal treatment plants. Nearly one million households rely on private on-site systems, and approximately 700,000 of them have flush toilets. Infiltration and drainfield systems are the most common types. More advanced systems with enhanced biological phosphorus reduction are increasing in number, but they still represent only a few percent of the total.

Owners of private sewage systems are required to monitor their functioning and to address faults. However, many people are unaware of the environmental impact of their sewage systems and lack motivation to correct or upgrade non-compliant systems. Because of this, municipalities have increased their supervision of on-site systems. Several municipalities also support cooperation projects that are paving the way for systems involving recirculation of the nutrients into agricultural land[5].

The current national POM based on the EU Water Framework Directive (WFD) requires authorities to enforce higher demands on the functioning of small wastewater systems and it prioritizes supervision of both small and large systems. The Swedish Agency for Marine and Water Management (SwAM) is continuing to develop steering instruments for the reduction of nitrogen and phosphorus emissions from small on-site sewage systems and to provide guidance for county administrative boards and municipalities concerning control and inspection of such systems.

2.1.4 MANY ACTORS WISH TO INFLUENCE AGRICULTURAL PRACTICES

After World War II, the agricultural sector in Sweden and many other countries began to change at a more rapid pace than before the war. The use of mineral fertilizers increased dramatically, and both crop production and animal farming was intensified. This led to higher production, but also to undesirable environmental effects. The first obvious signs of an ongoing eutrophication of Swedish coastal waters were noted in the Kattegat in the mid-1970s. Filamentous algae were washed ashore in large quantities, and this was attributed to leakage of nutrients from agricultural land[6]. Fish mortality due to oxygen deficiency was also reported, and, in 1983, the Swedish Environmental Protection Agency launched a research project on the causes of marine eutrophication. This project confirmed that leakage of nutrients from agricultural land is a major cause of marine eutrophication[7]. In addition, it created a scientific basis for measures to reduce nutrient fluxes into coastal waters.

The current rules and measures to reduce the leakage of nutrients from Swedish agricultural land have developed over a long period of time[8]. Already at the end of 1960s there were rules regarding the storage of manure. In the 1980s, a national goal to halve the nitrogen loads from all sectors into marine environments was established. The use of commercial fertilizers was reduced due to a fertilizer tax but also due to a decrease in the total area of arable land. Moreover, the maximum animal density on a farm was regulated[9]. When Sweden entered the EU in 1995, national rules had to be adapted to existing EU directives. For example, the Nitrates Directive (91/676/EEC) from 1991 required Sweden to declare nitrate vulnerable zones and to establish POMs to reduce nutrient leakage from agricultural land. During the past two decades, new EU directives have strengthened the need for international harmonization at the same time as the number of measures to reduce nutrient leakage from agriculture has increased. The following sections provide a brief overview of legislation, economic compensation, and information activities.

2.1.4.1 Legislation combines general and specific mandatory regulations

The Swedish Environmental Code[10] came into force in 1999, and it is applicable to all types of activities that might damage or influence the environment including agriculture. The Code applies to physical individuals as well as legal entities, like companies or organizations, regardless of sector. People who pursue an activity or measure (or plan to do so) need to show that they comply with general rules of considerations (Chapter 2), which are to have the necessary knowledge to avoid environmental damage, to take precautions to prevent damage (including using best available techniques), to avoid selling or using chemical products or biotechnical organisms if there are products or organisms that are assumed to be less dangerous to the environment, to conserve and reuse material, and to choose sites for their activities with the aim of minimizing environmental damage. These obligations are applicable if compliance cannot be deemed unreasonable. If damage or detriment occurs to human health or the environment, despite precautions having been taken, the actor is still responsible for remedying it.

In addition to the general rules, there are several more specific agricultural regulations issued by the Government or its expert authority the Swedish Board of Agriculture (SBoA). The most extensive measures are used only in zones designated as nitrate vulnerable. Mandatory measures for farmers in current regulations are[8]:

- *Storage of manure.* To optimize the nutrient efficiency, it is necessary to store manure over the seasons, which implies the need for storage capacity with no leakages. These rules are valid for farmers with more than 10 animal units (two units in nitrate vulnerable zones). The number of months a farmer needs to store the manure depends on location and type of animal.
- *Cover and refill of slurry containers.* The risk of ammonia losses into the atmosphere is reduced by placing a cover directly over the slurry container. For parts of Sweden, there are special requirements for how to refill slurry containers.
- *Spreading of slurry.* Major parts of the ammonia losses occur within the first hours after spreading the slurry. These losses must be reduced by turning down the slurry into the soil. When this is not possible due to growing crops, there are other techniques to use, some of which are compulsory in some parts of Sweden.
- *Limits in usage of manure.* Phosphorus use is limited to 22 kg for each hectare each year, counted as a five-year average. In nitrate vulnerable zones, nitrogen is limited to a total of 170 kg per hectare per year. In addition, the fertilization must not exceed the needs of the crops.
- *Spreading manure.* There are different precautionary rules concerning how and when to spread manure in different parts of Sweden. Important factors are whether the land is covered by water or snow, the distance in meters to water bodies, the inclination of the land, if it is winter season, and how soon the manure needs to be incorporated into the soil after being spread.
- *Rules regarding land to grow during fall and winter.* For specific parts of southern Sweden, 60% of the arable land should be under vegetative cover by specific crops between specific dates to avoid nutrient leakage.

2.1.4.2 Economic compensation

There are many operations (measures) that farmers and landowners can engage in voluntarily to reduce nutrient leakage. Farmers can apply for compensation for some of these activities from the Swedish (EU) Rural Development Programme (SRDP)[11], which includes support for a better environment. The support covers reduction of nitrogen leakage (by catch crops and spring tillage), riparian strips with extensive ley, management of wetlands, and cultivated grassland. There are also compensations available for measures within what is called selected environment consisting of targeted buffer zones, controlled drainage to be able to steer the groundwater level, structure liming, and creation/restoration of wetlands.

An evaluation of the SRDP, which ended 2013, found that it contributed to the Swedish Environmental Objectives and to Sweden's international obligations[12]. In the Rural Development Programme for 2014–2020, the compensations are aligned with the voluntary practices intended to be performed by farmers through the new POMs of the WFD from 2016.

2.1.4.3 Guidance and information

The SBoA employs local nutrient advisers in several parts of the country who coordinate local advisory services. The aim is to accomplish an adequate use of nutrients and feed to animals, to stimulate farming schemes that combine economic and environmental benefits, and to minimize the loss of ammonia from agricultural land. In addition, the long-term project Focus on Nutrients (in Swedish: *Greppa Näringen*) offers advice to motivate and inspire farmers to minimize their environmental impact. This project is set up in cooperation between SBoA, the County Administrative Boards (CABs), and the Federation of Swedish Farmers. In the project, the CABs hire and organize consultants that farmers can use free of charge. These consultants offer a number of alternative services to choose from (read more in English at Greppa.nu).

The SBoA also produces publications and other information regarding nutrients and manure handling in agriculture and horticulture. A computer program is offered as a tool to simulate the effects of alternative nutrient handling.

2.1.5 REDUCTION OF NUTRIENT EMISSIONS FROM SHIPPING AT SEVERAL LEVELS AND SCALES

Shipping influences eutrophication in the sea primarily by large emissions of nitrogen oxides (NOx) from fuel combustion but also by discharges of sewage. Shipping in the Baltic Sea is intense and it is increasing. Because visits to Swedish ports only represent part of the transports, and because the ships owned or operated from other countries are in the clear majority, Sweden and other countries need to cooperate to be able to influence the impact from shipping on eutrophication.

The Swedish Transport Agency (STA) is responsible under the government for rules, permissions, and inspections. The STA has taken several steps that influence eutrophication both nationally, regionally, and internationally. On a national level, Sweden introduced differentiated fairway dues in the mid-1980s, and ships that took measures to reduce NOx emissions received discounts. Sweden has worked actively with other neighboring countries in HELCOM and OSPAR to apply for the North Sea and the Baltic Sea to become Nitrogen Emission Control Areas (NECAs). The UN International Maritime Organization (IMO) has decided (and will finally determine in July 2017) that after 2021 newly built ships sailing in NECAs need to install technology that will reduce NOx emissions. To facilitate implementation of the NECA requirements, Sweden is currently working towards better and simpler certification rules for the NOx-reducing technology.

Sweden has also worked actively for an IMO ban of sewage discharge from passenger ships in the Baltic Sea. Within HELCOM, the sewage from ships has been on the agenda since the mid-1970s, and in 2011 the Baltic Sea was designated by the IMO as the first sea in the world to be a special area concerning sewage from ships. Consequently, from 2019 all new ships (and from 2021 old ships as well) sailing in the Baltic Sea are forbidden from dumping waste directly into the sea, and they need to have either their own treatment facilities on board or to deliver the sewage to the proper facilities when they are at ports[13]. Since 2015 it has also been forbidden to discharge sewage into the sea from leisure boats.

Within the framework of HELCOM, Sweden has also initiated cooperation between the Baltic Sea states with the aim to enable harmonized application of the regulations in the region. Moreover, Sweden is active in the work of the European Commission and other European states and stakeholders within the European Sustainable Shipping Forum[14].

2.1.6 OTHER MANAGERIAL ASPECTS

New measures decided upon by the state of Sweden with the primary aim to reduce eutrophication are now mainly based on two EU directives. POMs that primarily aim to improve inland and coastal waters and that address land-based sources for 2016–2021 have been set up in accordance with the Swedish regulation that implements the EU WFD (2000/60/EC). POMs to improve the open sea and that address sources in the open sea have been set up in accordance with the regulation that implements the EU Marine Strategy Framework Directive (MSFD) (2008/56/EC). Naturally, the land-based measures also have an impact on the marine waters.

WFD measures. The five River Basin District Authorities (RBDAs) in Sweden propose land-based measures to meet environmental quality standards. After public consultation, the POM is decided by the Water District Board, which is appointed by the Government. Because the RBDAs only have mandate to address other Swedish authorities, a POM is formally a chain of authorities and their respective responsibilities. However, when the concrete measures are implemented, they also affect businesses, farmers, industries, builders, and citizens in various ways.

In the current POM, the environmental status of water bodies is attended by a number of requests. The SBoA has been requested to develop guidance for inspection that is focused on CABs, municipalities, and companies with the aim to reduce losses of nutrients into bodies of water. The CABs, in turn, shall supervise or guide the municipalities so that operators are performing self-monitoring and have the capacity to assess the impact of the operations (or measures) on the status of the waters. Municipalities shall supervise operations with an influence on water bodies. Further on, since 2016, a new measure has been requested by SwAM, which is to develop instructions, guidance, and information for concrete measures that can be used to reduce the internal load and to reduce the concentrations of nutrients in water bodies with internal loads. The internal load of phosphorus comes from old sediment deposits leaking nutrients into the water above. The agency shall also work for the long-term establishment of direct nutrient-reducing measures in the seas and the coastal waters and shall follow up on the effectiveness of the measures[15].

As a complement to the POM of the WFD, there are also larger environmental projects organized by actors in Swedish water management. One example related to eutrophication is Life IP RICH WATERS[16], which engages 40 partners in addition to the responsible Swedish CAB. The 7-year project is co-financed by the EU (which provides 11 million euro of the project's 29-million-euro total budget), and the aim of the project is to make the POMs more efficient.

MSFD measures. Three measures to improve the open sea address sources in the open sea in accordance with the EU MSFD. They include the investigation of possibilities to influence the internal nutrient load in the sea, the investigation of financial compensation for net uptake of nitrogen and phosphorus from water by cultivating and harvesting blue catch crops, and the development of techniques for cultivating and refining blue catch crops and aquaculture that do not cause a net load.

Environmental Objectives. In addition to the measures and instruments mentioned above, Sweden also has 16 Environmental Objectives decided upon by the parliament. The government bears overall responsibility for these objectives, of which one is to reach zero eutrophication. This goal is concretized as: "Nutrient levels in soil and water must not be such that they adversely affect human health, the conditions for biological diversity or the possibility of varied use of land and water." All Swedish agencies shall work toward the Environmental Objectives, and their efforts are reported to the government (www.miljomal.se).

Voluntary action and private initiatives. Each actor or private citizen has a possibility to take personal responsibility for engaging in environmentally friendly actions. However, even though people in Sweden highly appreciate the sea, few of them know how they influence the sea or what to do to effectively minimize their negative impacts on the sea. Non-governmental organizations (NGOs) have important roles in supporting voluntary actions through awareness raising. For example, "The Meat Guide" is a tool to inform about the influence of various types of meat on climate and several other environmental aspects[17]. The Swedish Society for Nature Conservation (Naturskyddsföreningen) also campaigns to raise awareness of the drivers of eutrophication. The role of groups of neighbors and small associations are important, for example, in maintenance and upgrading of small on-site septic systems. Such initiatives can also obtain economic support.

Monitoring and research. On a regular basis, Sweden surveys and collects large amounts of data concerning how the land is used, cultivated, and fertilized. There are also monitoring programs for groundwater, lakes, rivers, and the sea, and deposition of airborne nitrogen is measured in the national monitoring program. In addition, there is extensive research related to the state of the sea and to identifying indicators to assess this. Research regarding measures and their effects to improve the state of the sea, however, is scarce.

International cooperation. Sweden cooperates in several constellations with other countries in the fight against eutrophication. HELCOM (Baltic Marine Environment Protection Commission - Helsinki Commission) is the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area, known as the Helsinki Convention. The Baltic Sea Action Plan (BSAP) is a common agreement between the member states and the EU to reduce nutrient load, with targets for each contracting state. The west coast of Sweden borders the North Sea. OSPAR (The Convention for the Protection of the Marine Environment of the North-East Atlantic) is the mechanism by which 15 governments and the EU cooperate to protect the marine environment of the Northeast Atlantic, including the North Sea. Since Sweden joined EU in 1995, the EU processes and directives have been directing much of the work.

2.1.6.1 General remarks

Over the past several decades, many measures to reduce eutrophication have been decided upon and enacted in several sectors. Installation of wastewater treatment systems is one important type of measures. Regulation, advice, and economic support regarding agricultural practices form another group of measures with positive effects on the nutrient load. On a national level, Sweden has reached balance regarding spreading and uptake of phosphorus on agricultural soil surfaces[18]. Evaluations of the combined measures used in the agricultural sector reveal that they contribute to the reduction of nutrient leakage[9].

The concentrations of both nitrogen and phosphorus have been reduced in some of the lakes in southern Sweden. Also, in regions dominated by agriculture the riverine loads to the sea show a downward trend, especially for nitrogen[19].

There have been considerable improvements in some coastal areas, but not in all Swedish coastal waters. Moreover, there are no major improvements in the open sea of the Baltic[20]. Using the current methods, Sweden will not reach its eutrophication goals established from the EU WFD or the MSFD on schedule.

2.2 MEASURES IN DENMARK

Agriculture in Denmark has long been focused on animal production, and Denmark is now one of the world's largest exporters of pig meat. The production is highly specialized, and around 5,000 farms produce approximately 28 million pigs annually[21]. This type of intensive agriculture implies that there is a significant risk for substantial nutrient losses to aquatic environments unless strict regulations are enforced.

2.2.1 MANDATORY PROGRAMS FOR THE ENTIRE TERRITORY

Agricultural nitrate pollution has been a major concern in environmental policy since the mid-1980s. This has resulted in a fairly complex and detailed set of regulations addressing non-point as well as point sources[22]. The first Aquatic Action Plan, adopted in 1987, resulted in major reductions of nitrate fluxes into water. Since then, the Danish nitrate regulations have been gradually strengthened to ensure implementation of the EU Nitrates Directive and the EU WFD.

The Nitrates Directive addresses agricultural nitrate pollution through a set of mandatory measures to be applied in the nitrate vulnerable zones, which are designated by the member states themselves. Denmark chose to adopt a whole-territory approach, implying that the entire country is regarded as nitrate vulnerable. As a consequence, the action programs are mandatory in the entire country. Actions include prohibition periods regarding fertilizer application, storage capacity for livestock manure equivalent to the longest prohibition period, limitations to the application of fertilizers based on a balance between foreseeable crop requirements and nitrogen supply from soil and fertilizers (balanced fertilization), and a maximum load of 170 kg N/ha/year of livestock manure[23]. If the mandatory measures are insufficient to achieve the objectives, the action programs must include additional measures not specified by the Nitrates Directive[23].

2.2.2 INDIVIDUAL FARMER PERMITS

The Danish fertilizer regulations combine detailed specification of agricultural practices and technology standards. For example, each farm must prepare a nitrogen budget by accounting for the crops grown on individual fields, their associated nitrogen norms, and the amount of fertilizer, including manure and other organic fertilizers, that is applied. Until recently, the fertilizer norms were set to a level that was 14–18% lower than the optimal norm for the crops. However, the justification of such tight norms was questioned, and site-specific approaches were suggested to enable more efficient reductions of undesirable nutrient fluxes[23]. From 2016, the rule of suboptimal fertilization has been cancelled. Currently, farmers can fertilize based on what is economically optimal (although this is still calculated by species and guided by a central committee). It has been agreed to introduce new measures such as the establishment of wetlands, further requests for catch crops, and the development of targeted measures, although the latter have still not been specified or implemented.

Prevailing restrictions for individual farmers are based on two different regulations. The Environmental Protection Act protects water that could be used for drinking water. Restrictions can be voluntary or ordered together with an economic compensation to avoid any undue interference with private property rights. The other regulation, The Act on Environmental Permits for Livestock Installations, should prevent pollution of nutrients in the aquatic environment. Through a permit system, individual farmers are restricted to a maximum load of nitrogen of 140–170 kg N/ha depending of the type of livestock, the sensitivity of the aquatic environment (three classes), and the retention capacity of the stock. Further, there is also a regulation on ammonia emissions for the protection of terrestrial nitrogen vulnerable habitats. However, because the permit system only includes animal manure and not fertilizer in general, it is unlikely to meet the environmental objectives[23].

2.2.3 STRUGGLE TO COMBINE INSTRUMENTS AND MEASURES DEVELOPED AT SEVERAL LEVELS

The Nitrates Directive aims at protecting water quality, not to achieving a specific environmental objective. On the other hand, the EU WFD objectives are expressed as environmental quality standards that must be achieved for individual water bodies. The WFD also requires a structured process with objectives, monitoring, and POMs that are adapted every six years.

The first Danish WFD program from 2009 was based on the Agreement on Green Growth, which incorporated a Danish environmental and nature plan up to 2020 along with a strategy for encouraging the development of a green agriculture and food industry. The WFD program contained new reduction goals and mandatory measures such as the establishment of riparian zones along all watercourses, additional use of catch crops, and restoration of 10,000 hectares of wetlands. However, the targets and measures were challenged, and the regulation was highly contested[23]. Proposals were raised that farmers should be able to use measures in a more flexible manner, and a new water management plan has been created. The 2015 political decision called “Landbrugspakken” (the agricultural package) introduced new possibilities and requirements that imply more flexible and voluntary measures for farmers.

2.2.4 GENERAL REMARKS

Denmark has been addressing the leakage of nutrients from agriculture for a long period of time. The regulations that started in the 1980s were able to reduce the agricultural nitrate pollution to the marine environment by almost 50% from 1985 to 2003[22]. The ongoing initiatives with water management plans and river basin management plans for 2015 to 2021 are expected to lead to further reductions of land-based sources of nutrients[24]. However, the improvement of water quality in coastal waters is lagging behind[22], even though a recent study shows signs of improvements, for example, in the southwestern basins of the Baltic Sea (Arkona Basin)[25]. There is currently an intense political debate about measures to further reduce eutrophication, and the previous and current systems are being partly_replaced by new systems targeted towards spatially differentiated regulations. In addition, there is a political ambition to expand the measures from the cultivated area to the edge of the field or further downstream, or even to the receiving coastal waters.

2.3 EUROPEAN UNION – LEGISLATION AND FINANCING

The EU is an economic and political union between 28 European countries that together cover much of the continent. The EU is based on the rule of law, and everything it does is founded on treaties that are voluntarily and democratically agreed upon by its member states. Since the 1970s, the EU has agreed on over 200 pieces of legislation designed to protect the environment.

The major environmental challenges facing Europe have evolved since the early days of European environmental policymaking. In the 1970s and 1980s, the focus was on traditional environmental themes such as protecting species and improving the quality of the air we breathe or the water we drink by reducing emissions of pollutants. Now the emphasis is on a more systematic approach that takes account of the links between various themes and their global dimensions. Moreover, management strategies are moving from remediation to prevention of environmental degradation.

Some of the EU Directives for water and marine quality exemplify this development:

- The Bathing Water Directive (76/160/EEC) as revised (2006/7/EC).
- The Drinking Water Directive (80/778/EEC) as revised (98/83/EC).
- The Directive Concerning Urban Wastewater Treatment (91/271/EEC).
- The Nitrates Directive (91/676/EEC). Each country needs to designate their nitrate vulnerable zones and to establish POMs with the aim of reducing nutrient leakage from agricultural land.
- The Water Framework Directive (2000/60/EC). The aim is to establish and maintain Good Environmental Status in all lakes, groundwater, and coastal waters. In six-year cycles, goals are decided upon in the form of environmental quality norms, the implementation of measures, and status monitoring.
- The Marine Strategy Framework Directive (2008/56/EC). The aim is to establish and maintain Good Environmental Status in the sea. The directive requests a six-year cycle of assessment, goal-setting, decisions of measures, and implementation.

The EU provides funding for a broad range of projects and programs covering the following areas:

- regional and urban development
- employment and social inclusion
- agriculture and rural development
- maritime and fisheries policies
- research and innovation
- humanitarian aid

Several of these can be used to support activities that might mitigate eutrophication (see more at http://europa.eu/european-union/about-eu/funding-grants, and the project LIFE IP in section 2.1.4).

2.3.1 GENERAL REMARKS

By EU legislation, all countries establish common terminologies, methods, and time plans that support national efforts. Through financial support, there is a redistribution of economic sources that can enable environmental measures in countries with less financial resources, for example, by establishing wastewater treatment plants that will lead to an improved common sea.

2.4 THE HELSINKI CONVENTION

The Convention on the Protection of the Marine Environment of the Baltic Sea Area, known as the Helsinki Convention, is one of the four European Regional Sea Conventions (RSCs) under the UNEP umbrella. HELCOM (Baltic Marine Environment Protection Commission - Helsinki Commission) is the governing body. The nine countries around the sea are contracting parties, and the EU is the tenth partner.

HELCOM was originally set up in the 1970s with a focus on harmful substances such as oil spills. At the end of 1980s, problems with eutrophication became more obvious, and the commission worked with the first assessment of the total load of organic matter (BOD, COD) and nutrients (nitrogen and phosphorus) being released into the Baltic Sea.

For those HELCOM Contracting Parties that are also EU member states, the EU MSFD establishes a framework within which the member states shall take the necessary measures to achieve or maintain Good Environmental Status (GES) of the marine environment by the year 2020 at the latest. However, it is important to note that HELCOM also reaches beyond the EU, which makes the work within HELCOM important because the Russian Federation is one of its member states.

The HELCOM Baltic Sea Action Plan (BSAP) is an ambitious program to restore GES in the Baltic Sea by 2021. The Plan, adopted in 2007 and updated in 2013, provides a concrete basis for HELCOM work[26]. It integrates the scientific knowledge and management approaches into strategic policy implementation, and it stimulates goal-oriented multilateral cooperation in the Baltic Sea region. The plan includes reduction targets for the member states' nutrient inputs into the Baltic Sea that also take into account transboundary inputs from surrounding states (i.e. states with no actual coastline along the Baltic sea), which emphasizes the need for multilateral cooperation even outside HELCOM member states.

HELCOM plays an important coordinating role by raising awareness of the eutrophication problem and suggesting possible mitigation measures to decision-makers, stakeholders, and the general public, as well as directing the monitoring of nutrient inputs and concentrations in the Baltic Sea. Important follow-up tools for the convention are annual and periodic assessments. Also, the regional indicators that have recently been developed are important instruments for assessing the eutrophication status as well as inputs of nutrients. All assessments are aimed at ensuring that the mitigation actions taken at all levels to combat eutrophication and other threats to the GES in the Baltic Sea areas are effective and that detrimental impacts are reduced. The assessments are also aimed to help the contracting parties that are also EU member states to report the progress of their POMs according to the EU MSFD.

Although actual mitigating measures generally are taken nationally or even regionally within countries, a lot might be gained by coordinating the measures and monitoring their effects on a higher level. Because the water in the Baltic Sea does not respect national borders, it is quite evident that measures need to be taken jointly. Also, the effects and the possibilities for general acceptance increase if the measures are taken mutually. For example, the concomitant NECA applications from HELCOM and OSPAR (see below) ensure equivalent regulation of NOx from shipping over the two Regional Sea Convention Areas. This is a very important regulatory tool because shipping has been steadily increasing over the last decades and is a major source of atmospheric deposition of nitrogen in these two sea areas and is thus a major threat regarding the eutrophication of the seas[27,28]. The importance of the joint effort is illustrated by anticipated reductions in NOx emissions in the Northeast Atlantic that are also expected to have a significant impact on the Baltic Sea because a substantial part of the atmospheric nitrogen deposition in the Baltic Sea originates from North Sea shipping[28,29].

An important achievement is the significant reduction of so-called hot spots within HELCOM. From a list of the originally depicted 162 point sources of special concern in 1992, 118 have been removed from the list[30]. In particular, the improvement of sewage handling and treatment in the city of St. Petersburg is a major achievement. With its 5 million inhabitants, St. Petersburg is by far the largest city in the Baltic Sea catchment area, and proper sewage handling is of high importance for the environment in the Gulf of Finland and for the whole Baltic Sea. Sweden and Finland have contributed together with the Nordic Investment Bank, and local Russian financing ensured the progress towards fulfilling the HELCOM recommendations on wastewater treatment quality. The additional removal of five hot spots in the St. Petersburg area of the Russian Federation has been discussed recently.

A major challenge to mitigating eutrophication within the Baltic Sea is how to reduce the impact from internal phosphorus loads, i.e. old sediment deposits leaking nutrients into the water above. This multifaceted task includes measures in the open sea, even in international waters, which requires cooperation. However, the situation with oxygen-poor bottom waters increasing the phosphorus leakage is partly caused by the decaying organic material originating from the eutrophic sea and partly by the sporadic inflow of oxygen-rich water from the Northeast Atlantic.

Other important regional players in the work to protect and improve the Baltic Sea environment are foundations like John Nurminen, NEFCO (Nordic Environment Finance Corporation), and BalticSea2020, which aim to financially support projects within the Baltic Sea area. NEFCO has proposed a nutrient quota and credit-trading system for the HELCOM countries similar to the EU CO_2-trading scheme to counteract climate change[31]. In addition, the BONUS research program, funded by the majority of the HELCOM member states and the EU, is funding large transnational and often multidisciplinary research projects striving at an economically and ecologically prosperous Baltic Sea region. Also, the Russian Federation participates in BONUS through a bilateral agreement that further strengthens the outreach and the impact of the research.

2.4.1 GENERAL REMARKS

Decisions in HELCOM are not imperative for the countries, and this situation might facilitate discussions and agreements. Through the common objectives established by the member countries in HELCOM, they can collaborate more efficiently. The convention is also useful for the harmonization of indicators, the development of methods to assess environmental status, etc. Other important benefits are the exchange and buildup of knowledge and data as well as the development of national POMs. The collaboration of the nine countries in HELCOM has also been useful in dialogues with global actors such as the IMO. The HELCOM work has not covered the exploration of societal drivers or measures to address such drivers. Currently, there is evidence that the total nutrient inputs have decreased to the levels of the 1950s[32].

3 THE NORTH SEA

The North Sea is partly surrounded by some of Europe's most densely populated land areas. This has resulted in considerable pressure on the marine ecosystems, including excessive inputs of nutrients from urban areas, agriculture, and shipping. To protect and restore the ecosystems of the Greater North Sea and four other regions in the North-East Atlantic, 15 countries and the EU have signed and ratified an international sea convention called the Oslo-Paris Convention, or OSPAR. This chapter pays special attention to measures against eutrophication in the Netherlands because this country has a very long tradition of water management and intensive, highly developed agriculture. Thereafter, the OSPAR convention and its strengths and weaknesses are briefly described.

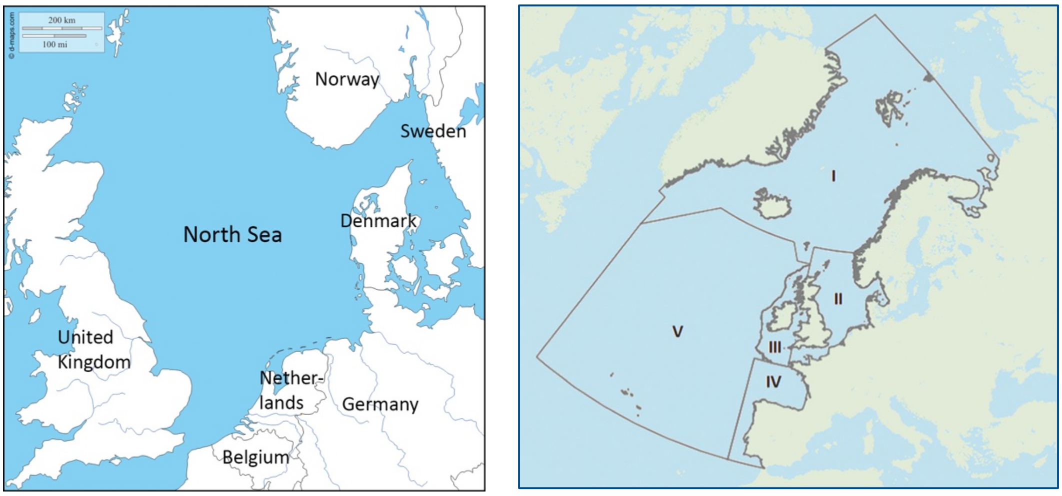

Figure 3. Maps of the North Sea and the OSPAR regions (I: Arctic Waters, II: Greater North Sea, III: Celtic Seas, IV: Bay of Biscay and Iberian Coast, and V: Wider Atlantic). Sources: www.d-maps.com (see References) and the Swedish Agency for Marine and Water Management.

3.1 MEASURES IN THE NETHERLANDS

The Netherlands is one of the world's largest exporters of agricultural and food products. More than 60-billion-euro worth of vegetables, fruits, flowers, meat, and dairy products are exported each year. This high production and export is enabled by a high input of commercial fertilizers and a large import of animal feed. Livestock production generates considerably more manure than is required by agriculture in the immediate vicinity. As a consequence, the cycling of nutrients is disrupted and eutrophication of aquatic environments is widespread in the Netherlands. Vegetable production takes place in more or less closed systems with high nutrient use efficiency, but such operations can result in eutrophication where the products are consumed and sewage is handled.

Recent statistics indicate that the average nitrogen surplus (i.e. the difference between the input into agricultural land and the amount taken up the crops) in the Netherlands is about 120 kg per hectare per year[1]. The phosphorus surplus is about 12 kg per hectare per year. General trends towards higher intensity in animal farming and spatial separation of animal farming and crop production will strengthen the regional nutrient imbalances unless powerful measures are taken.

3.1.1 REGULATION OF LIVESTOCK PRODUCTION

Because of its high livestock density, the Netherlands has taken several measures to reduce nutrient losses into the environment. Most of the measures are national initiatives, but EU directives, especially the Nitrates Directive and the Water Framework Directive, have also been compelling (see below).

In the 1980s, several permit systems were introduced. The numbers of animals were limited by national production rights for pigs and poultry and by EU milk quotas. Furthermore, a fertilizer act was introduced in which nearly every phase of manure production and application was governed by numerous ministerial regulations and governmental decrees[2]. In 1990, a soil protection act entered into force, and a new decree on fertilizer use was issued. To further strengthen the efforts to restore equilibrium between the supply and removal of phosphorus and nitrogen in soil and water, a mineral accounting system at the farm level was introduced in 1993. This system required farmers to carry out detailed bookkeeping of nutrients and included a penalty for nutrient losses.

In 2003, the European Court of Justice ruled that The Netherlands Action Programme, of which the mineral accounting system was part, was in conflict with the EU Nitrates Directive. Three years later, this resulted in new application standards for manure as well as mineral fertilizers. In general, the new application rates were lower than those practiced under the old accounting system[3].

Low-emission housing of animals in newly built structures was enacted in 2007. Processing of excess manure became mandatory in 2014. Farmers are now required to have a percentage of their surplus manure treated for sale outside the Dutch fertilizer market. It is expected that this will result in the export of nutrients to regions with less intensive livestock farming and possibly also development of new products based on the extraction of valuable organic components from manure.

3.1.2 IMPLEMENTATION OF EU DIRECTIVES

The EU Nitrates Directive that entered into force in 1991 provided legally binding rules for the maximum annual application of manure. For nitrate vulnerable zones, the directive sets 170 kg as the maximum annual limit of nitrogen from livestock manure that can be applied per hectare. However, the Netherlands successfully applied for an allowance of nitrogen inputs from manure to a maximum of 250 kg per year and hectare on dairy farms where at least 70% of land is in use as grassland. This derogation was from 2015 onwards changed to 230 kg per year per hectare in some areas[4].

The EU WFD, which was adopted in 2000, implied a shift in focus from agricultural practices to other measures such as better performance of wastewater treatment plants and adjusted hydro-morphology. This is noteworthy considering that agriculture is responsible for about 65% of the current nutrient load to Dutch surface waters. It also noteworthy that, with the policies currently in place, the expected reduction of nutrient pollution will not be sufficient to reach the general goals of the Nitrates Directive and the WFD.

The Dutch POM to mitigate eutrophication of coastal waters within the Marine Strategy Framework Directive (MSFD) is essentially a summary of measures taken to fulfill other EU directives. Assuming that the WFD objectives are achieved, it is estimated that the GES for nutrients will be within reach in the years after 2020 in accordance with the MSFD. In addition, it is emphasized that very few eutrophication phenomena occur in the Dutch sector of the North Sea[5].

3.1.3 GENERAL REMARKS

The Netherlands is in many respects a world leader in agriculture and food production, and Dutch research and knowledge building regarding nutrient management is widely recognized. The Netherlands has also introduced a multitude of regulations and decrees to reduce the loss of nutrients to aquatic environments. Nevertheless, there are still structural problems that await sustainable solutions. The measures implemented so far have reduced, but not eliminated, the nutrient surpluses in Dutch animal farming.

3.2 THE OSPAR CONVENTION

The Oslo-Paris (OSPAR) convention is a Regional Sea Convention (RSC) under which 15 national governments and the EU cooperate to protect the marine environment of the Northeast Atlantic.

The presence of serious eutrophication in parts of the maritime area during the 1970s led North Sea countries to agree on the need for a reduction of nitrogen and phosphorus inputs in areas affected by, or likely to be affected by, eutrophication. Agreement was reached on a target for reduction of the order of 50% between 1985 and 1995. Nitrogen discharges are the main problem, especially from agriculture[6]. Nutrient discharges and losses from point and diffuse sources to waters affected by eutrophication have steadily decreased over the past 20 to 25 years. However, by the last assessment in 2008 the 50% reduction target had mostly been met for phosphorus but not for nitrogen.

The governing body, the OSPAR commission, is the coordinating platform for regional implementation of the EU MSFD in the Northeast Atlantic. The work of the OSPAR commission strives among other things to support harmonized national marine strategies for achieving GES[7], and the work is coordinated with activities in the Helsinki Commission (HELCOM) for the Baltic Sea. Much of the recent work on measures to control nutrient inputs has been taken into framework of European legislation.

Concern about atmospheric nitrogen inputs is increasing, and in 2016 the North Sea states in parallel with the Baltic Sea countries in HELCOM applied to the IMO for the North Sea and the Baltic Sea to become a so-called NECA (Nitrogen-Oxide Emission Control Area), which aims to reduce nitrogen emissions from shipping.

Important follow-up tools for the convention are periodic assessments of eutrophication status based on an agreed common procedure for eutrophication status assessment. This is supported by regional indicators of nutrient pressure and effects that have recently been adopted. Together these are important instruments for assessing the eutrophication status as well as inputs of nutrients in the North Sea just as in the Baltic Sea (see HELCOM above). All of these assessment tools aim to follow whether the mitigation actions to combat eutrophication and other threats to the GES in the North Sea areas are effective and to check that detrimental impacts are reduced. The assessments feed into holistic multi- thematic OSPAR Assessments, such as the Intermediate Assessment 2017 and the next QSR (Quality Status Report) in OSPAR that help the contracting parties that also are EU member states to report on the development of environmental status in relation to their POMs according to the EU MSFD.

3.2.1 GENERAL REMARKS

The Northeast Atlantic covers a vast area, and the sea is not a closed basin. Hence, discharges of nutrients do not necessarily affect the polluter, and there can be a perception that the sea can receive large amounts of nitrogen and phosphorus without consequences. However, eutrophication is not always a local problem. Water masses continuously move and interact, and the associated transport of nutrients can lead to eutrophication effects at great distance from the source. Although the extent of eutrophication has declined in the OSPAR region since 1990, concerns remain about atmospheric and riverine inputs of nutrients. Eutrophication still exists in areas of the North Sea and Celtic Seas that are sensitive to nutrient inputs such as estuaries, fjords and bights, and areas affected by river plumes.

4 THE GULF OF MEXICO AND THE CHESAPEAKE BAY

The Gulf of Mexico was included in this study because it has a large dead zone that receives runoff from about 40% of the whole territory of the US. The Chesapeake Bay was included because it has played a key role in raising awareness of marine eutrophication.

Figure 4. Maps of the Gulf of Mexico and the Mississippi River basin.
Sources: www.d-maps.com (see References) and United States Environmental Protection Agency, www.epa.gov (see References).

Figure 5. Map of the Chesapeake Bay Source: www.chesapeakebay.net (see References).

4.1 LEGAL AND INSTITUTIONAL FRAMEWORK IN THE US

In the 1960s, numerous reports about unswimmable, unfishable, and nearly dead lakes and watercourses paved the way for more powerful water management. The Environmental Protection Agency (EPA) was established in 1970. Soon afterwards, the Federal Pollution Control Act, usually referred to as the 1972 Clean Water Act, was passed by Congress. In this act, national goals to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters" were established. In addition, a state grant program was launched to support the construction of sewage treatment plants, and a National Pollution Discharge Elimination System (NPDES) was established to give out permits for point-source emissions. Point sources of nutrients that are regulated by the NPDES program now include municipal and industrial wastewater treatment plants, concentrated animal feeding operations (CAFOs), and various other sources.

The amendments to the Clean Water Act that were passed in 1987 implied that non-point-source pollution and problems in estuaries needed to be more actively addressed and that specific toxic pollutants and leaching of nutrients from agricultural land receive more attention. Current approaches to address non-point pollution include assessment of total maximum daily load (TMDL) for a body of water.

The calculated TMDL is a cap on the sum of estimated point emissions, diffuse emissions and a safety margin that is determined necessary to restore or maintain a water body that is currently impaired. As a general matter, states are responsible for developing TMDLs and submitting them to EPA for approval. A trading system is allowed which can provide greater flexibility to reduce overall compliance costs, and encourage voluntary participation of unregulated actors (e.g., crop farmers) contributing to nonpoint emissions within the watershed.

4.2 DISCONNECTION OF CROP PRODUCTION AND ANIMAL FARMING

In the 1950s, industrialization of agriculture began to take off in North America, Australia, and certain parts of Europe. The scale and intensity of production increased, and the dependence on commercial fertilizers and other off-farm products grew stronger[1,2]. In addition, this transformation was accompanied by a significant regional reallocation of agricultural production in which animal operations were disconnected from crop production. The upper Midwest shifted from animal to crop agriculture, whereas other regions further south favored animal production. Corn and soybeans were shipped far away to feed animals, and due to incomplete recycling of manure, nutrients gradually accumulated in areas with high animal density[3,4].

The development of the US broiler industry illustrates how dramatically a food chain can change in a few decades[5]. Advances in housing, breeding, and disease control enabled large and highly mechanized production in a relatively small area. Many breeding operations and chicken processing plants were established close to major population centers or in regions offering cheap labor, and access to locally produced feedstuff was considered less important. Also, hog production and cattle operations went through a radical but somewhat slower transformation. Improved housing, disease control, and feeding allowed specialization and meat production in large buildings and feedlots.

4.3 THE CHESAPEAKE BAY PROGRAM

The Chesapeake Bay Watershed (CBW) on the east coast has long been the subject of intensive research on marine eutrophication and has a long tradition of water management. The Chesapeake Bay Program[6], which was established in 1983, has become a world-renowned program for science, restoration, and partnership. It is managed by EPA through the Chesapeake Bay Program Office and is staffed by employees from a number of federal and state agencies, non-profit organizations and academic institutions.

The measures taken to restore the Chesapeake Bay are based on a source-to-sea concept and are characterized by active stakeholder participation. Written agreements are used to guide the restoration of the estuary and its watershed. By setting goals and tracking progress, partners can be held accountable for their work. By developing new agreements over time, it can be ensured that restoration efforts are based on the best available science.

Recent assessments show clear improvements in some areas but cannot conceal the fact that the Bay's ecosystem remains in poor condition. Moreover, the targets regarding nutrient inputs have not been reached. Although agricultural runoff has been significantly reduced in the past few decades it is still the single largest source of nutrient and sediment pollution entering the Bay. A review of management options for sustainable livestock production in the CBW emphasizes that the single greatest challenge facing livestock operators in the CBW remains the accumulation of nutrients, especially phosphorus, on farms.

4.4 THE MISSISSIPPI RIVER/GULF OF MEXICO WATERSHED NUTRIENT TASK FORCE

The Gulf of Mexico has long had a large hypoxic zone. In fact, it is now considered to be the largest hypoxic zone in the Western Hemisphere[7]. The Mississippi River is by far the largest source of nutrients entering the Gulf, and this makes it natural to have a joint management strategy for the Mississippi River Basin and the Gulf of Mexico.

In 1997, the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force was established. The role of the Task Force, which includes federal and state agencies, is to provide executive level direction and support for coordinating the actions of participating organizations working on nutrient management within the Mississippi River/Gulf of Mexico Watershed. A Coordinating Committee facilitates coordination of all sub-committees and working groups, and makes recommendations to the Task Force for action. The group is responsible for ensuring that all actions complement each other and that communication flows effectively to all sub-committees and working groups.

In 2001, an action plan was adopted to reduce the area of the hypoxic zone to less than 5,000 km^2. Seven years later, a revised action plan was released to reduce, mitigate, and control hypoxia in the northern part of the Gulf of Mexico and to improve water quality in the Mississippi River Basin[8]. Current programs to reduce undesirable eutrophication effects emphasize the role of nutrient strategies covering the entire watershed and the importance of improved partnerships and new management approaches. Universities, farmers, agricultural organizations, businesses, cities, communities, and NGOs are mentioned as potential members of new partnerships. Voluntary initiatives and cooperation play a key role.

A recent assessment of progress showed that there has been no significant reduction in nutrient loads delivered to the Gulf of Mexico between 2001 and the present time[9]. Nor has the area of the hypoxic zone in the Gulf of Mexico been reduced. Further work will focus on implementation of the adopted strategies.

4.5 GENERAL REMARKS

The Chesapeake Bay and the Mississippi River/Gulf of Mexico Watershed programs are being implemented in different spatial scales. This might explain some differences in the present outcomes of the two programs. A large water body takes a long time to restore, and decision makers who live far from the sea might be less motivated to engage in the restoration of marine ecosystems. Nevertheless, the two programs have several noteworthy similarities.

First, considerable attention is paid to outreach activities, and both programs have high ambitions to engage a wide range of stakeholders. Moreover, voluntary actions and cooperation between stakeholders have a high priority.

Second, both programs have long had a strong focus on point emissions, including emissions from concentrated animal feeding operations. Diffuse emissions could potentially be mitigated through a trading system, but this has not been widely implemented. Some states require farmers to follow nutrient management plans when fertilizing crops and managing animal manure (e.g. Maryland[10]). However, eutrophication of marine waters still remains a major problem.

Third, the overall progress to reduce fundamental imbalances in nutrient fluxes in food production is slow. It can also be noted that neither of the two programs focus on the societal driving forces behind the present structure of the food and agriculture sector, including the role of consumers, grocery stores, retailers, and other actors in the food sector.

5 THE BAY OF BENGAL

The Bay of Bengal (BoB) is one of the largest marine ecosystems in the world where the risk of undesirable coastal eutrophication is particularly acute[1]. It receives huge amounts of runoff from many rivers that carry increasingly large loads of nutrients, especially nitrogen. This can, at least in an initial phase, lead to higher productivity. However, a newly found 60,000 km^2 hypoxic zone indicates nitrogen imbalance[2]. The area also suffers from other severe pressures such as overexploitation of marine resources.

The eight countries enclosing the BoB are India, Bangladesh, Sri Lanka, Maldives, Myanmar (also known as Burma), Thailand, Indonesia, and Malaysia, and about 400 million people live in the catchment area[3]. In the following sections, measures against eutrophication in the two countries with the largest populations (Bangladesh and India) in the catchment area are reviewed. In addition, a recent regional initiative to cooperate in saving the BoB from environmental degradation is reviewed.

Figure 6. Map of the Bay of Bengal. Source: www.d-maps.com (see References).

5.1 MEASURES IN BANGLADESH

Bangladesh has a coastline with many rivers and distributaries. The country, which became independent in 1971, has a growing population of about 160 million people (see Appendix), and is densely populated and predominantly rural, with 105 million people living in rural areas (2015). Lately, there has been an explosive urban growth, especially of the capital city with approximately 15 million now living in the greater Dhaka area. The urban part of the Bangladeshi population represented 34% of the total in 2015 compared with 20% in 1990 (see Appendix).

With the growing economy and population in Bangladesh, ensuring the safety of water resources and groundwater is essential for the country. The quality of the water in the many rivers in Bangladesh is influenced by pollution from activities in the upstream country of India.

5.1.1 AGRICULTURE

With the aim to reduce hunger and reach food self-sufficiency, new agricultural technologies were introduced from the 1960s. The combination of new varieties of high-yielding seed, flood controls, irrigation projects, introduction of fertilizers and pesticides led to an increase in food-grain productions from 10 to 37 million tons between 1972 and 2010, the green revolution[4]. Bangladesh is a fertile land, and the agriculture sector, with rice as the most important crop, is of major importance for the economy. Agriculture uses about 60% percent of the land in the coastal zone, although expansion of shrimp farms has taken over some agricultural lands[5].

In coastal areas of Bangladesh, farmers grow less fertilizer-responsive rice varieties. Hence, only low amounts of nutrients should currently be exported to the coastal environment due to fertilizer use[5]. On the other hand, fertilizer use is increasing on a national level (see Appendix).

5.1.2 AQUACULTURE PRACTICES LEADING TO COASTAL POLLUTION

Shrimp is a large export product, and about 4.8 million people are directly dependent on this sector[6]. Studies have indicated that both mineral fertilizers and manure contribute to the nutrient levels of the shrimp ponds and that a significant amount of the nutrients are accumulated in sediments[7]. Mortality incidents in shrimp farms are believed to be due to harmful algae. In addition, fish kills have been associated with the appearance of harmful algal blooms[5].

Many of the cities and towns in Bangladesh contain swamps and lakes that are used for informal aquaculture activities by local residents, and the majority of these water bodies are contaminated with fecal matter[8].

5.1.3 LIMITED TREATMENT OF DOMESTIC SEWAGE

A third of Dhaka city has wastewater collection and treatment facilities, while another third uses septic tanks. Most of the untreated or inadequately treated wastewater directly or indirectly reaches the river systems through different canals, drains, and estuaries and eventually flows into the BoB Sewage from nearly 36 million people living in 19 coastal districts directly or indirectly goes into the water systems (rivers). In fact, none of the coastal cities have proper sewage systems or sewage treatment plants in place, although sewage treatment systems are being planned in several urban centers[5].

5.1.4 GENERAL REMARKS

With a growing population and limited resources, other concerns than eutrophication of the open sea are being prioritized. Growth and poverty reduction are among such concerns. Health aspects and the improvement of sanitation is another concern, and programs have been developed to increase awareness and personal responsibility. There are national legal and policy frameworks as well as action plans related to eutrophication, although their implementation seems to be less complete[5].

5.2 MEASURES IN INDIA

India is in rapid transition from a developing to a developed country. The population has increased rapidly to 1.28 billion people in 2015 compared to 955 million in 1990. Currently, approximately 30% live in urban areas, which are growing rapidly through migration. Related to this are challenges such as freshwater shortages, sewage overloads, groundwater depletion, and pollution.

India has relatively extensive information on nutrients in coastal waters provided by the Central Pollution Control Board (CPCB) that is part of the Ministry of Environment. The river runoff into the BoB has a strong influence on the productivity of the coastal waters[9]. However, the total loads from different sectors, such as agriculture, sewage, aquaculture, and industry, are usually not available[5].

5.2.1 AGRICULTURE

India has always been an agrarian country but prior to 1960s India was also dependent on agricultural imports. A program of agricultural improvement, the Green Revolution, with better seed, more fertilizer, improved irrigation and education of farmers led to growth in food-grain production. By the early 1990s, India was self-sufficient in food-grain production. The major proportion of the irrigation water in the agriculture sector is abstracted from groundwater[5]. Farmers are also dependent on wastewater or wastewater-polluted sources for irrigation. Moreover, the agricultural sector in India is using increasing amounts of fertilizers (see Appendix).

5.2.2 AQUACULTURE PRACTICES

Aquaculture in India generally uses low to moderate levels of inputs, especially organic-based fertilizers and feed. Since the 1990s, there has been a huge increase in the construction of brackish water ponds for shrimp aquaculture, and large areas along the coast have been converted into aquaculture farms. In 2012, shrimp accounted for around 50% of the value of seafood in India. There are various reports about the pollution loads due to shrimp aquaculture, especially after harvest when the ponds are emptied. Problems of algal overgrowth in receiving waters are indicative of nutrients originating from aquaculture wastes[,10,11,12,13].

5.2.3 LIMITED TREATMENT OF DOMESTIC SEWAGE

The volume of wastewater has increased with the population, urbanization, improved living conditions, and economic development. Modern treatment capacity exists for only about 21% of the generated sewage (269 plants). Approximately 31% of wastewater from the larger cities (Class I and II) is treated, although the existing treatment capacity is plagued with operational and maintenance problems[14].

Currently, the CPCB is promoting decentralized treatment of sewage at the local level using technology based on natural processes. This “Land Treatment” involves a controlled process in which pre-treated wastewater achieves a degree of treatment by bio-geochemical processes so the water can be reused[15]. This method differs from age-old farming practices in which uncontrolled wastewater is used for irrigation and fertilization.

The coastal cities of Chennai (Tamil Nadu) and Kolkata (previously Calcutta, Wes Bengal), with a combined population of 6 million people, on the east coast generate large amounts of wastewater. Since the 1930s, large wetlands east of Kolkata have been used to recycle wastewater in combination with the production of fish. This treatment is used for almost one third of the sewage generated by Kolkata[14]. It is clear that if the wastewater generated by the larger cities is treated properly before disposal a large proportion of the coastal pollution due to municipal waste disposal would be addressed. The wastewater from metropolitan areas and cities located on the coast is mostly disposed of into creeks, canals, or backwaters[13], and the wastewater treatment plants cannot meet the increasing pace of wastewater generation[15].

5.2.4 RAISING PUBLIC AWARENESS

In order to raise awareness among the public on the levels of marine pollution in the country, the Ministry of Earth Sciences has decided to publish the levels of pollution-indicative parameters for a number of locations at least every three months or as the data are collected.

5.2.5 GENERAL REMARKS

India has a large and growing population with increasing urbanization. Hence, food supply and sanitation are highly prioritized. Even though national legal and policy plans for mitigation of eutrophication were decided upon many years ago, they are not always implemented.

5.3 BAY OF BENGAL TRANSBOUNDARY PROJECT

The Bay of Bengal Large Marine Ecosystem Project (BOBLME) was initiated in 2009 because action was needed to address fish problems and to combat eutrophication but no already existing body had a clear mandate to support a regional initiative. The BOBLME project laid the foundation for a coordinated program of action between the countries and was designed to improve the lives of the coastal population through improved regional management of the BoB environment and its fisheries. A continuation of the BOBLME project, which ended in 2015, has been discussed but not yet decided on.

The project included a series of reviews, analyses, and consultations aiming at establishing strategic action programs. The initial Transboundary Diagnostic Analysis identified major issues affecting the health of the BoB. The main causes of pollution and poor water quality were identified to be[3]:

- discharge of untreated or inadequately treated domestic, industrial, and agricultural wastewater
- inadequate solid waste management, including solid waste disposal and open burning of solid waste
- increasing emission of nutrients from fertilizer use in agriculture
- atmospheric emissions from industry and fossil fuel burning

In addition, some of the underlying reasons were declared to be increasing coastal population density and urbanization; inadequate investment in wastewater management and wastewater treatment; lack of awareness by policy makers, the legal system, and civil society; lack of enforcement of environmental regulations; and increasing per capita consumption and waste generation[3].

The project identified 400 potential actions to improve the overall situation. These include national as well as transboundary actions. Among these, each country identified actions that were already undertaken, actions it would need assistance for, and actions not considered in the near future. The actions selected by each country constitute a national action program. Actions that four or more countries aimed to start or needed to strengthen were put on a list for "coordinated capacity development" actions.

Actions undertaken in the areas cover:

- Institutional arrangements and legal and policy reforms
- Management measures
- Knowledge strengthening, awareness, and communication
- Human capacity development

Three objectives related to the coastal and marine pollution were accepted by seven (of the eight) countries in the strategic action program[3]. The targets for each object were:

1. To reduce the discharge of untreated sewage and wastewater into river, coastal, and marine water. The goal is a 5% increase in the number of towns connected to sewage treatment systems by 2025 and that 100% of the effluents discharged from treatment systems should meet national standards by 2025.
2. Reduce solid waste and marine litter. The goal is a 5% reduction in solid waste disposal by 2025, a 5% reduction in plastics and e-waste by 2025, the establishment of solid waste management systems in coastal regions, extended responsibility of producers, and a 10% increase in municipal waste collection by 2025.
3. Reduce and control nutrient loading in coastal waters. The goal is to improve nutrient use efficiency at the source in agriculture, aquaculture, and other nutrient-generating industries by 10% by 2025, to reduce nitrates and phosphates from wastewater by 50% by 2025, and to safely reuse 100% of recovered sludge by 2025.

5.3.1 GENERAL REMARKS

The process of preparing a second phase of the BOBLME project is ongoing. There is a dependency on contributions from external partners such as those previously involved, including the Food and Agriculture Organization (FAO), the Global Environment Facility (GEF), Norway, the Swedish International Development Cooperation Agency (SIDA), and the National Oceanic and Atmospheric Administration (NOAA) in the US. Long-term commitment on mitigating eutrophication in the BoB is not ensured as long as the institutional framework is not in place.

6 THE EAST CHINA SEA

The East China Sea is a marginal sea of the Pacific that is bounded by China to the west and south, Korea to the north, and Japan to the east (figure 7). It is connected with the South China Sea in the southwest, the Yellow Sea to the north, and the Sea of Japan to the northeast. The major part of the East China Sea consists of a continental shelf off of mainland China. This shelf is also the main recipient of freshwater from surrounding land areas. The Yangtze River (Changjiang) alone is responsible for 90–95% of the freshwater inflow[1], and it drains a river basin with a population of more than 400 million people. This large population and the dramatic societal changes that have recently taken place in China make the East China Sea an interesting example of the challenges to mitigate eutrophication in the presence of strong societal trends.

Figure 7. Maps of the East China Sea and the Yangtze River basin. Sources: www.d-maps.com and WWF (see References).

During the past three decades, China has witnessed unprecedented economic growth. Compilations of official statistics show that the average income was tenfold higher in 2013 than in 1983[2]. In this period, the food supply was also dramatically improved, and life expectancy increased from 66 to 77 years. However, these obvious advancements have been accompanied by environmental degradation. Over-enrichment of nutrients in Chinese inland and coastal waters is one of the environmental problems that has increased and may continue to further increase.

Numerous Chinese lakes, especially those located in agricultural regions, are strongly affected by nutrient enrichment[3,4]. Measurements of riverine loads of nutrients into Chinese coastal waters reveal a strong upward trend that has not yet been curbed[5,6], and atmospheric deposition of nitrogen has become the single largest nitrogen source for many offshore regions along the east coast of China[7]. Model calculations confirm the long-term increase in nutrient loads and raise concerns about further increases in the coming decades[8]. The ecological effects of increased nutrient loads in coastal waters include harmful algal blooms along the Chinese coast and increased areas of hypoxic bottom water, especially off the Yangtze River estuary[9].

6.1 SOCIETAL DRIVING FORCES BEHIND MARINE EUTROPHICATION

Analyses of societal changes and nutrient fluxes in China show that the following four factors have contributed more than others to the high nutrient loads in freshwaters and coastal waters: population growth, urbanization, human dietary shifts (increased meat consumption), and disconnection of crop and animal production[7,10,11.] In addition, aquaculture constitutes a significant and expanding cause of coastal nutrient enrichment[12,13].

The growth of the total population of China has now leveled off, but urbanization is still very rapid (see Appendix, Table 3). Meat consumption increased from 14 kg to 61 kg per capita per year between 1980 and 2013[14], and there are still no indications that it will curb at levels substantially lower than those prevailing in Europe and North America. Moreover, agriculture has been subjected to rapid industrialization characterized by a high input of commercial fertilizers in crop production and meat production in concentrated animal feeding operations. In 2014, China's total consumption of nitrogen fertilizers reached 31 million tonnes, and the national average annual application rate (about 290 kg N per hectare arable land) was substantially higher than in Europe and North America (see Appendix, Table 7). Together, this indicates that the loads of nutrients into Chinese coastal waters, and especially the East China Sea, will continue to increase unless very powerful measures are introduced to curb the present trends.

6.2 THE ENVIRONMENTAL PROTECTION LAW

A new Environmental Protection Law entered into force in China in 2015. This law describes in general terms which environmental issues shall be addressed and how the responsibility is shared between the national government and government agencies at the provincial and local levels. The national level shall promote clean production and resource cycling and set national environmental quality and technology standards. Enterprises, public institutions, and other producers or business operators that discharge pollutants shall pay pollution fees. The agencies at the provincial level shall allocate funds for the protection of drinking water sources, the treatment of domestic sewage and other waste, and pollution prevention and control for livestock and poultry breeding.

6.3 AGRICULTURAL POLICIES AND THEIR EFFICIENCY

As a complement to the general Environmental Protection Law, several more specific national policies and regulations have been introduced to promote sustainable agricultural production in China. For example, the rapidly growing livestock production accentuated the need for a "Discharge Standard of Pollutants for Livestock and Poultry Breeding", and such a standard was introduced in polluted areas in 2003.

The system to control emissions from concentrated animal feeding operations (CAFOs) implies that all such operations must go through the regulatory scheme in the Water Pollution Law. Before a large CAFO may be built, the Department of Agriculture and the Ministry of Environmental Protection must develop a livestock husbandry plan that takes into account the carrying capacity of the environment. Next, those two departments must develop a plan for the prevention and control of pollution from livestock and poultry breeding[15].

Nutrient use efficiency in Chinese agriculture is another issue that has been addressed. Several studies of the input and output of nutrients in different steps of the food chain have demonstrated that the nitrogen and phosphorus use efficiencies are very low because of poor nutrient management[16]. It has also been noted that the nutrient efficiencies of Chinese food production are much lower than in the EU and the US[17]. The Ministry of Agriculture has responded by introducing the "Zero Growth in Synthetic Fertilizer Use from 2020 Onwards" policy. This policy instrument includes specific reduction targets for synthetic fertilizer use, manure recycling, and nutrient management for the period 2015–2020.

A recent research report concludes that the policy aimed at zero growth in fertilizer use is a good start but not very effective in reducing nutrient pollution[18]. Improved manure management and animal production with lower nutrient excretion are also needed. Another study emphasizes the crucial role of reducing direct discharges of manure into aquatic environments[19].

6.4 URBAN WASTEWATER TREATMENT IN CHINA

With the growing concern about environmental pollution in China, the construction of wastewater treatment plants has been given more and more attention. From 2007 to 2012 the number of plants increased from 1,258 to 3,340[20]. The removal of organic matter measured as chemical oxygen demand is good (80–90%) regardless of treatment processes, while nutrient removal is generally lower and varies more between plants.

The provincial environmental protection board is responsible for determining which standard to apply for a municipal wastewater treatment plant. Secondary treatment (i.e., involving biological treatment) is a minimum requirement for all cities. Higher standards (Class 1A) are required for plants discharging into sensitive receiving water bodies, and meeting such standards requires additional treatment to reduce nutrients and suspended solids. A recent report about the current status of urban wastewater treatment plants in China shows that although new treatment plants are being built at a high pace, the implementation of discharge standards has been low[21]. This is especially true regarding advanced nutrient removal.

The large amounts of sludge produced and the poor management of this form of waste raises significant concerns. A relatively recent report states that more than 80% of sludge in China is disposed of by improper dumping[22]. Although per capita production of sludge in China is lower than in most developed countries, this will lead to a large-scale accumulation of nutrients, especially phosphorus, in urban areas. Incomplete and sometimes unrealistic laws and regulations have been mentioned as significant causes of the present situation[22].

6.5 GENERAL REMARKS

The new Environmental Protection Law of the People's Republic of China, special regulations of CAFOs and sewage treatment, and initiatives like "Zero Growth in Synthetics Fertilizer Use from 2020 Onwards" indicate an increasing willingness to mitigate marine eutrophication without sacrificing food security. However, measurements of water quality and modeling of nutrient fluxes show that the implementation of measures to prevent harmful nutrient inputs into the East China Sea is lagging behind the influx of nutrients. This can partly be explained by limited resources to enforce current legislation and higher priority of issues other than nutrient pollution. Moreover, the role of private enterprises and consumers in the mitigation of marine eutrophication is unclear. Together, this indicates that the impact of urbanization, transitions in agriculture, and dietary shifts are so strong that fundamental imbalances in nutrient fluxes will persist for a long time.

7 METHODS TO EXPAND THE RANGE OF INTERVENTION OPTIONS

The fact that human pressure on many marine environments remains unacceptably high even though several measures have already been implemented indicates that there is a need to expand the range of intervention options. In this section, we present methods to systematically explore the set of actors in society who can influence undesirable inputs of substances into the sea by changing their behaviors or activities.

7.1 SYSTEMS ANALYSIS OF THE FLOW OF SUBSTANCES AND GOODS IN SOCIETY

The pressure on the marine environment can in many cases be described as a flow of substances or materials through society into the sea. However, from a societal perspective, a substance flow is not only a physical flow but also a result of a number of activities and behavioral patterns of institutions, organizations, and individuals. The conceptual flow model illustrated in figure 8 represents a first step to disclose and describe links between physical flows and processes in society. The model is generic in the sense that it can be applied to flows of substances as well as products and to systems delineated by different types of boundaries. Furthermore, the model emphasizes the key role of trade and consumption of products and allows for systematic analyses of behaviors and actors that shape the market of consumer products.

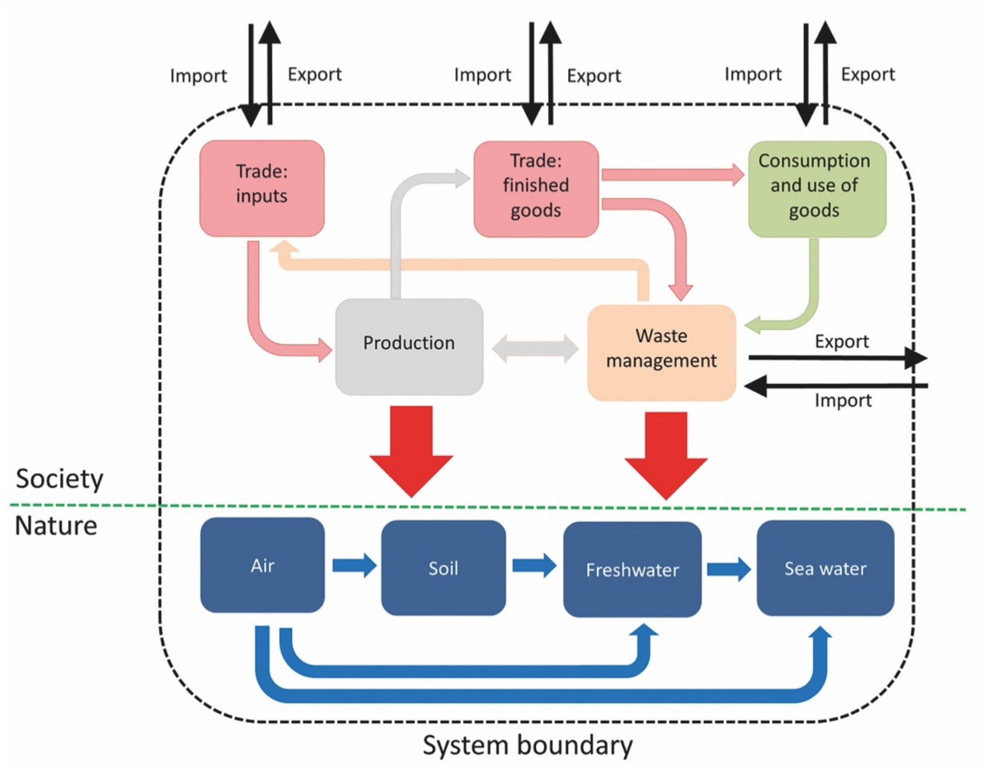

Figure 8. Generic model of the flow of substances and products through society and subsequent emissions into the environment. (Source: Sundblad et al., 2015)

The case of phosphorus flows through Sweden can illustrate how the model in figure 8 should be interpreted and used. Starting in the upper left corner of the graph, the node labeled *Trade:*

inputs illustrates that phosphorus fertilizers are imported into Sweden and sold to farmers. The farmers then use the fertilizers to produce crops (an activity in the *Production* node) that after various types of processing (additional activities in the *Production* node) are brought to a wholesaler or grocery store that markets the products (*Trade: finished goods*) to the consumer (*Consumption and use of goods*). Alternatively, if the crop is used as animal feed, the farmer brings the harvest to meat farmers (trade within the *Production* node). After the animals are slaughtered and the meat processed, merchant actors bring the products to the consumers. After human consumption of the food, the resulting waste is handled in municipal or on-site systems for liquid or solid wastes (*Waste management*). A substantial fraction of the phosphorus that is not recirculated into new production will leach into aquatic environments and finally reach the sea.

For more detailed descriptions of flows of goods and substances, the resolution of the flow scheme in figure 8 can be increased. This is illustrated in figure 9, where already published data regarding phosphorus flows in Sweden are compiled. The color coding of the nodes is the same as in figure 8. Larger flows, exceeding 1,000 tonnes per year, are indicated by bold arrows, and the estimated sizes of such flows are shown in the yellow boxes.

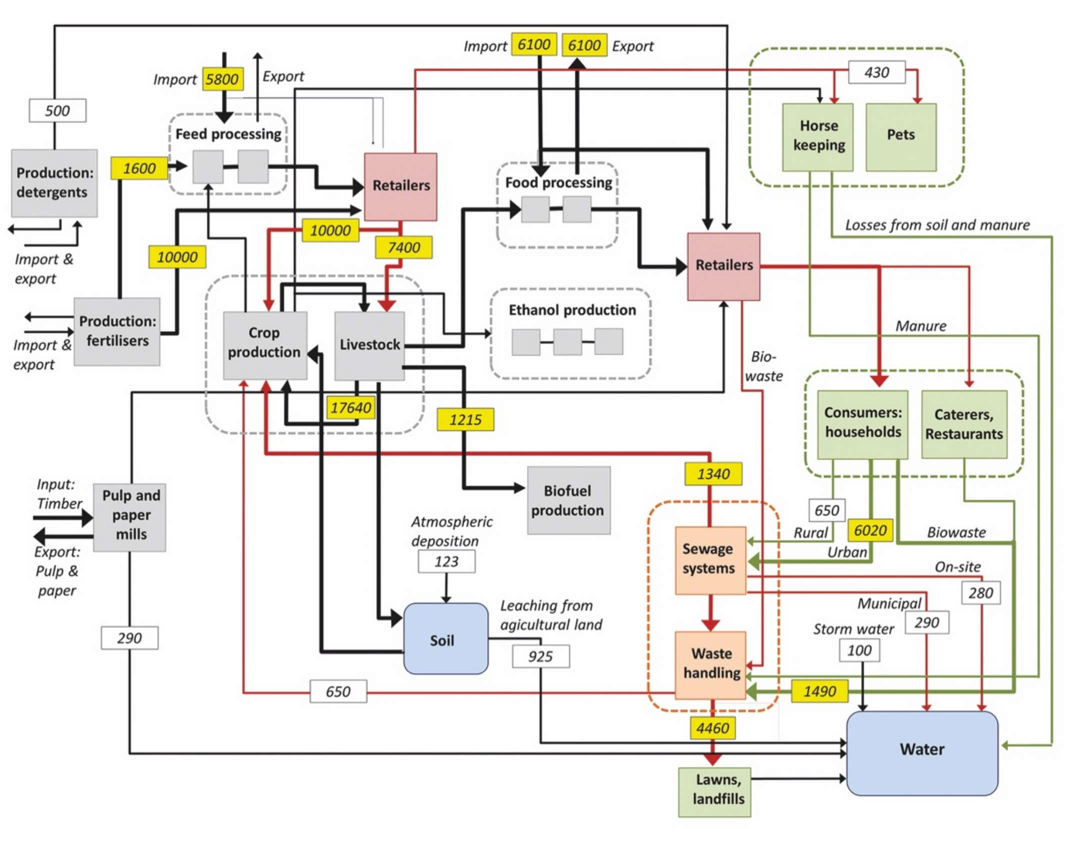

Figure 9. Flow of phosphorus through Sweden expressed in tonnes per year. Data from Linderholm & Mattsson (2013) and Ejhed et al. (2011) representing the conditions in 2010–2011.

The main benefit of substance analyses is that they provide information about the magnitude of different physical flows. Such information can then be used to direct the efforts in subsequent steps to identify relevant groups of actors. In the case of phosphorus flows in Sweden, previous studies have drawn attention to the food and agriculture sector, the production of pulp and paper, and emissions from both municipal wastewater treatment plants and on-site sewage systems[4]. The system view illustrated in figure 8 complements these studies by highlighting the role of actor groups, such as professional buyers and sellers, consumers, and proprietors of on-site sewage systems.

7.2 LINKING OF ACTORS AND BEHAVIORS TO PHYSICAL FLOWS

When developing measures to reduce the pressure on marine environments, it is important to identify actors with the potential to change their behavior so that the pressure is lowered. Substance flow analyses can help identify relevant groups of such actors. However, the identification of specific members of such actor groups usually requires more specific analyses of specific products and the activities that influence the flow of these products through society.

A case study of the product chain for Swedish beef was carried out to illustrate how specific and potentially influential actors can be identified. This product chain includes a large number of nodes and stretches from production and procurement of inputs for beef production to the handling of waste resulting from beef consumption (see figure 10). Closer examination revealed that even though the number of nodes is large, the total number of influential actors is moderate. Typically, most individual nodes have only one or very few organizations that dominate the market. The case study also revealed that large inputs of phosphorus (and nitrogen) into the sea originate mainly from cultivation of animal feed, animal farming, and handling of waste from human consumption of food.

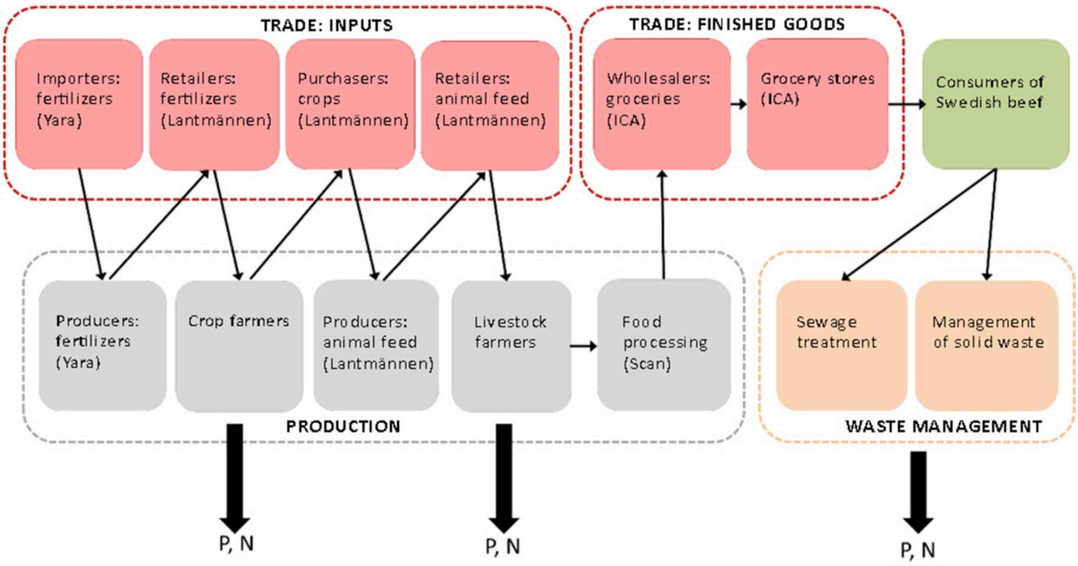

Figure 10. Chain of actors involved in the production, trade with inputs and finished goods, consumption, and waste handling related to Swedish beef. Thin arrows represent flows of products and waste between the various nodes. Bold arrows represent major pathways for inputs of nutrients (phosphorus and nitrogen) into the sea. Examples of Swedish companies involved in the activities are shown in parentheses.

The main benefit of product chain analysis is that specific actors can be identified and subsequently targeted in the development of POMs. In particular, such analyses can draw attention to the role of actors who influence substance flows indirectly through procurement and supply chain management. The case study of Swedish beef clearly shows that there are large food retailers that can influence what is consumed and thus the load of nutrients transferred into the Baltic Sea.

7.3 IDENTIFICATION OF ADDITIONAL ACTORS USING SOCIAL NETWORK ANALYSIS

When humans make decisions, they are almost invariably influenced by other persons or actors in society. Accordingly, a social network analysis of the actors already identified in the working process can help reveal additional actors. A social network analysis can be based on survey data, as demonstrated by Wallin et al (2013), who asked proprietors of on-site sewage systems which actors influenced their willingness to replace existing sewage systems with more efficient systems. With a limited number of key actors, structured interviews can be a more appropriate method. This approach was employed when the study of the product chain for beef was followed up with interviews with representatives from two market-leading organizations (Lantmännen and ICA) within the Swedish agriculture and food sectors. The interviews were focused on the self-image of these organizations regarding their impact on eutrophication, their preparedness to change their behavior, and the networks they have with other organizations.

Lantmännen is an agricultural cooperative owned by nearly 30,000 Swedish farmers. It operates as a retailer of fertilizers, crops, and animal feed and is also a major producer of grain-based food. ICA is the dominant grocery retail chain in Sweden, holding about 50% of the Swedish food market. The interviews with representatives from these two organizations demonstrated that they have networks of other organizations with which they discuss environmental and sustainability issues. Some network members are environmental NGOs. Others are trade organizations or projects that carry out research and development, for example *Focus on Nutrients*[6]. The nutrient-related discussions they hold with their network members, as seen in figure 11, are primarily focused on the reuse of sludge from wastewater treatment plants. Sludge is rich in nutrients, but the exact composition cannot be controlled, and drug residues and other substances represent risks. The lack of precise guidelines regarding sludge use is a major concern.

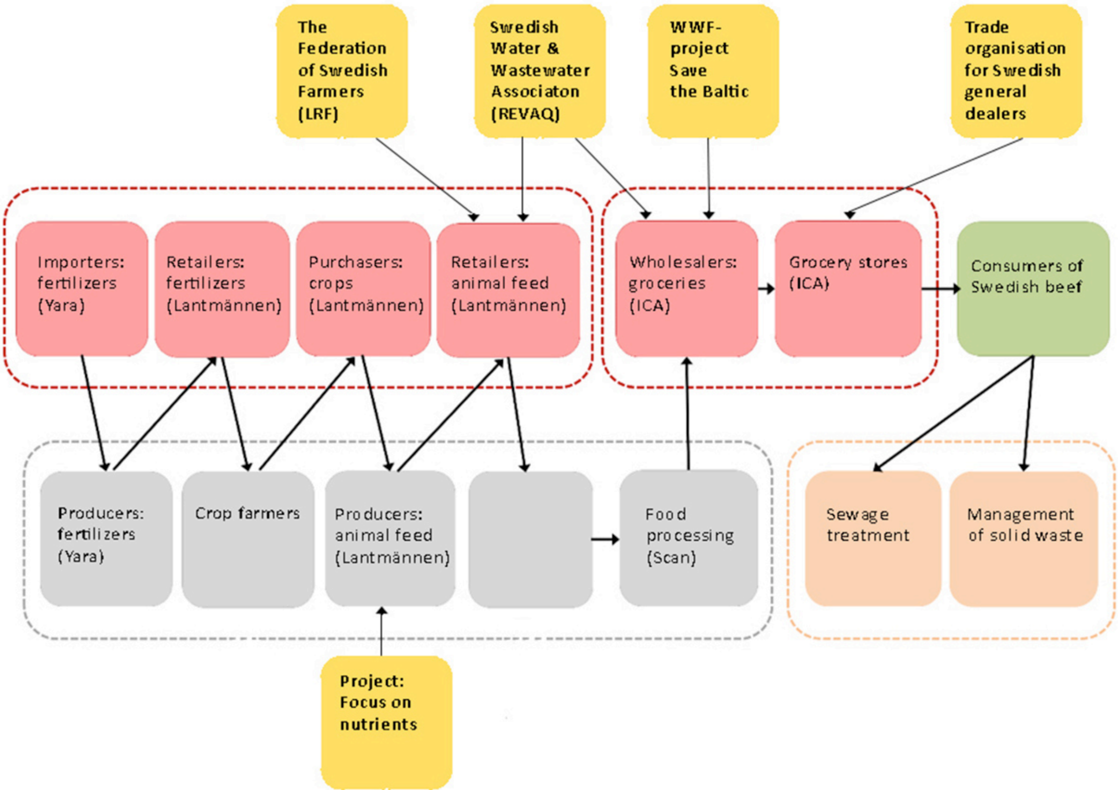

Figure 11. Flow chart of the product chain for Swedish beef expanded with actors (yellow nodes) that two market-leading organizations mention as social network members in issues related to loads of nutrients and eutrophication.

7.4 NEW INTERVENTION OPTIONS

The case study of production and consumption of beef refers to a specific product chain in Sweden. However, the method used to identify relevant actors and thereby also to expand the range of intervention options is very general. Moreover, the identification of actors needs to be followed by assessments of how changes in the behavior of actors can contribute to altered fluxes of nutrients into the sea. In Chapter 8, we examine how nutrient loads into the sea can be influenced by dietary changes and, in particular, protein consumption. The role of food consumption is also in focus in Chapter 9 about potential structural and technological changes in aquacultures. Chapter 10 draws attention to the potential to recover phosphorus from sewage sludge and thereby contribute to improved recirculation of this element.

8 POTENTIAL IMPACT OF DIETARY CHANGES ON NUTRIENT FLUXES

The past decades of economic growth in large parts of the world have been accompanied by considerable dietary changes. Statistics from FAO (see Appendix) show that there is an almost worldwide trend towards higher protein consumption. Moreover, an increasing fraction of the protein is of animal origin. The case study of Swedish beef consumption presented in chapter 7 reveals that inputs into the sea can be influenced by a large number of actors in supply chains. In this chapter, it is estimated how much the nutrient fluxes into the sea might be reduced if consumers adjust their total intake of protein to levels motivated by health reasons. The numerical calculations refer to Sweden[1], but are relevant also for other countries with a substantial overconsumption of protein. The per capita intake of animal protein in Sweden is now about 55% higher than in 1970[2,3,4]. Since protein-rich products, such as meat, fish, eggs, and cheese, are high in nitrogen and often also in phosphorus this change has not been favorable for the marine environment. On the other hand, if diets have changed substantially over the past few decades, maybe it is possible to act pro-environmental by adjusting the diets again.

In the current diet, Swedes eat on average 108 g per day of protein, which is higher than required from a nutritional point of view[5]. The current average diet (year 2009) includes a daily consumption of 174 g of meat counted as raw bone-free meat[6,7,8]. Pork accounts for the largest amount (79 g), followed by beef, chicken, and lamb (50 g, 40 g, and 5 g, respectively). In addition, the average diet includes 39 g fish, 28 g eggs, 840 g dairy products, and 15 g beans, which includes peas, lentils, and tofu. Because there are substantial differences in nutrient emissions among the products, it is worthwhile to consider the effect on the marine environment of alternative diets.

Three alternative diets with 60 g of high-protein food were compared with the current diet of 80 g high-protein food per day per capita[1]. One diet, called Recommended, is based on guidelines from the Swedish National Food Agency and includes less processed meat, red meat, and saturated fat. A Climate-smart diet replaces beef for chicken (except for the cows needed to produce dairy products). In the High legume diet, meat is excluded (except for the minimum number of animals to get the raw material for dairy products). Figure 12 shows the mix of food in the four diets.

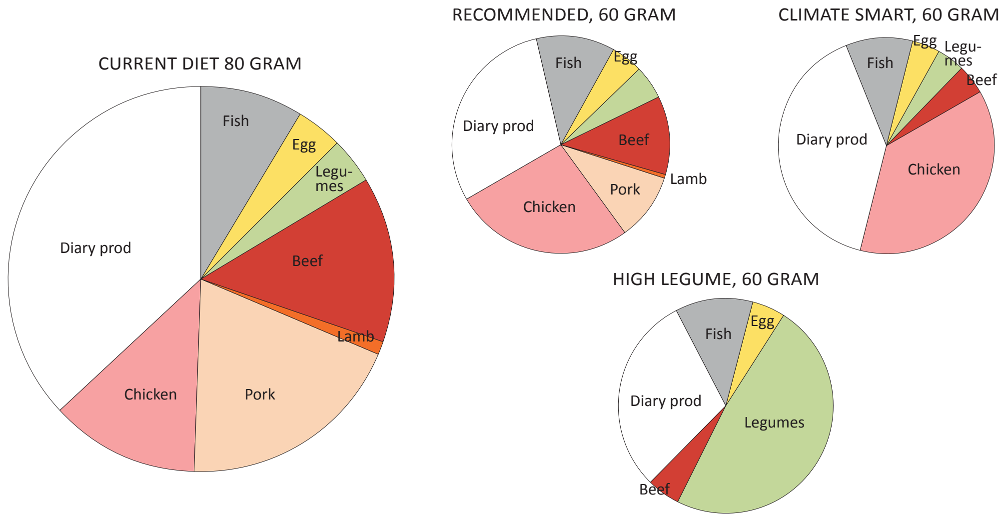

Figure 12: Daily intake of protein via protein-rich foods: 80 g of protein-rich food in the current diet and 60 g in the alternative diets.

The high legume diet produced the least phosphorus and nitrogen emissions among the three investigated diets. However, the differences between the three alternative diets were not very big as can be seen in Figure 13, which shows nitrogen reduction for the three alternative diets.

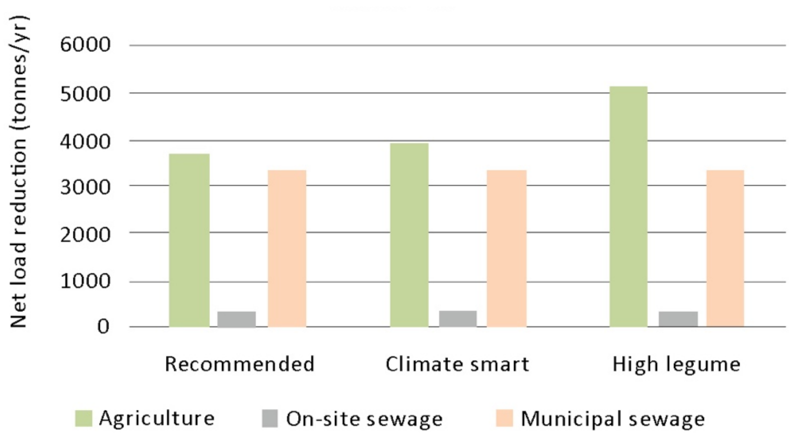

Figure 13. Potential reduction of nitrogen load into the sea if the total Swedish population changes to an alternative diet of 60 g protein per day per capita. Nutrient reduction load is specified for agricultural production and sewage systems.

More important is that all three alternative diets represent major reductions of net loads. Hence, if all Swedish people on average reduce their intake of protein-rich food from 80 g to 60 g each day, the total yearly reduction of nitrogen is between 7,300 and 8,800 tonnes per year. This would be a substantial reduction and more than the promises made by Sweden in international forums[1].

It is important to clarify that these figures represent potentials based on assumptions and simplifications. However, they do reveal that it is possible for people to influence nutrient load into the sea through their dietary choices.

What will it take to make this happen? Even if all citizens had the knowledge needed and also the intention to change, it can hardly be expected that their consumption will change in this way on a voluntary basis. The strength of habits as well as too many other projects and conflicting priorities will likely interfere with such ambitions if the change is not supported.

As shown in Chapter 7, the possibilities to influence and support such changes are in the hands of many actors. In a country like Sweden that is democratic and market oriented, anyone has the right to act, including politicians, national agencies, market actors, NGOs, and private citizens. In some markets, a limited number of companies represent a major part of the trade, and this puts them in a strong position to influence the situation. Examples of actors that influence food habits in Sweden are the food chains, deliverers of readymade meals, companies that sell weekly supplies of food over the Internet, and TV chefs.

This example might also indicate what is relevant in many other countries. People in many countries have increased their average protein consumption to levels far higher than needed (see Appendix).

9 AQUACULTURE WITH A MINIMAL LOSS OF NUTRIENTS

The previous chapters dealt with possible transitions of nutrient fluxes driven by general dietary changes and the behavior of various actors in the food sector. Aquaculture has also been mentioned, but thus far only as a source of nutrient pollution. This chapter draws attention to aquaculture as a particularly promising segment of the food sector.

Aquaculture can probably more than any other segment of the food sector revolutionize the global food supply. In 2014, a milestone was reached when inland and marine fish farming for the first time contributed more than wild-caught fish to the global supply of fish for human consumption (figure 13). In addition, there is a substantial and rapidly growing production of farmed shellfish and farmed aquatic plants.

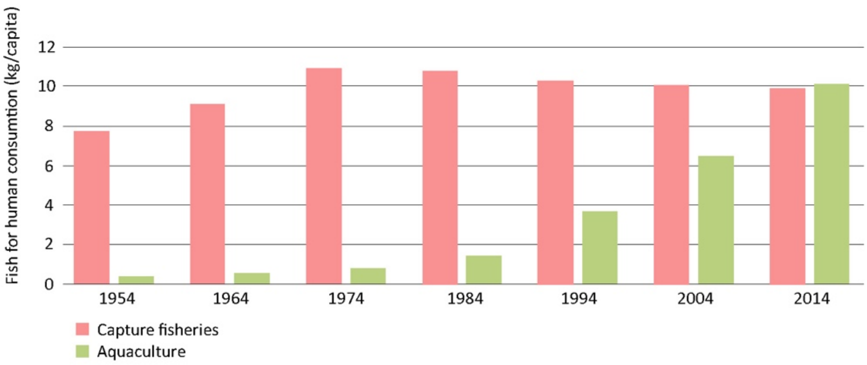

Figure 13. Contribution of wild-caught and farmed fish to the global supply of fish for human consumption (Source: FAO, The State of World Fisheries and Aquaculture 2016).

Due to the rapid growth of aquaculture, the global per capita consumption of fish has approximately doubled since the 1960s. It is generally agreed that this is beneficial from a nutritional point of view. Fish farming can also be a very efficient way of producing easily digested high-quality proteins containing all essential amino acids. In properly designed and managed systems, the feed conversion ratio (FCR) can be as low as 1.2 for salmon and even lower for other fish species. In other words, only about 1.2 kg of feed can be needed to increase the body mass of the farmed fish by 1 kg[2]. Animal farming in agriculture normally has a substantially less efficient feed conversion. For the broiler chicken, which is an efficient feed converter, the FCR is about 1.6, and for pig farming the FCR is usually about 3.

The efficient feed conversion in many aquaculture systems indicates that such systems can be favorable also from an environmental point of view. However, the negative effects are far from negligible. Intensive fishing for species used to feed farmed salmon and other carnivorous fish species can be a threat to marine ecosystems. Moreover, animals that escape from aquacultures can spread pathogens to wild populations. Water pollution is another issue that needs to be addressed. Some fish farming systems use large quantities of antibiotics and anti-fouling agents that are lost to the water. Moreover, large amounts of nutrients are lost to the water because the nitrogen and phosphorus use efficiency of open aquacultures is remarkably low. Detailed studies of two salmon cages in Norway showed that only 24% of feed phosphorus and

43% of feed nitrogen were retained as fish biomass[3]. Compilation of data from 330 aquacultures in China showed that even lower fractions of the nutrients in the feed were retained. Phosphorus use efficiency ranged from 8.7% to 21.2%, whereas nitrogen use efficiency ranged from 11.7% to 27.7%[4].

Due to widespread production of fish and crustaceans in systems with unsatisfactory nutrient management, it has been argued that marine aquaculture is, in fact, a significant and expanding cause of eutrophication of coastal waters[5]. The farmed animals produce substantial amounts of solid and dissolved excreta, and in more or less open systems such nutrients are lost to the surrounding waters. Undigested feed can be another source of nutrient losses to the environment.

Non-fed cultures of mollusks are generally positive for the marine environment because such aquacultures remove nutrients from over-enriched waters. However, there might be local negative effects. Because mollusks normally have a low nutrient use efficiency, farming of such animals can, in fact, become sources of specific forms of nitrogen and phosphorus. At worst, non-fed aquacultures can act as pumps transforming nutrients in algal biomass into dissolved nutrients that can cause harmful algal blooms[6].

In the following, we briefly review emerging aquaculture technologies that can make substantial contributions to the food supply without having unacceptable effects on marine ecosystems. Direct nutrient emissions from the aquacultures will be in focus, but a comprehensive analysis must also take into account emissions prior to or after the farming. Nutrients can leach into the water during the production of animal feed, and emissions from sewage systems are influenced by the food we consume.

9.1 CLOSED CONTAINMENT SYSTEMS

In order to minimize the environmental effects of aquaculture, it is important to have good control of the inputs and outputs of the system. This requires that the farmed animals are kept in some kind of closed containment that is separated from the outside environment by a tight barrier. Land-based systems can be designed as almost closed systems in which most of the water is recirculated after passing through some kind of filter. The recycling of nutrients can be particularly effective if fish farming is combined with greenhouse production of vegetables. Sea-based systems with floating tanks are typically designed as semi-closed systems. Clean water is pumped into the tanks from the surrounding sea, and solid pollutants are recovered as sludge before the water from the aquaculture is released back into the sea.

Land-based, recirculating aquaculture systems (RAS) have significant potential because they do not require access to waters suitable for conventional aquaculture. In addition, they:

- Provide possibilities for complete control of the rearing environment
- Eliminate the risk of fish escapees
- Eliminate the risk of external threats, such as harmful algal blooms
- Have the potential for disease-free production
- Can be located close to markets

Extensive pilot scale projects in the US, Canada, and Norway have demonstrated that it is technically feasible to produce high quality, market-size salmon (*Salmo salar*) in land-based RAS[7]. Sturgeon, steelhead, tilapia, and turbot are other examples of fish species successfully farmed in such systems. Some pilot-scale facilities have also demonstrated that it is technically feasible to recover both solid and soluble nutrients in hybrid agricultural-aquacultural systems. Commercial small-scale systems for integrated production of fish and vegetables exist in the US, Canada, Australia, and some other countries such as Sweden.

Productions costs for land-based RAS are usually higher than for sea-based systems[8], but recent estimates of production costs for salmon in Norway indicate that this gap is now almost closed. Currently, there are a handful of projects, mostly European, with a capacity of 1,000–2,000 tonnes/year that are selling salmon produced to harvest size in land-based facilities[9]. Larger facilities (> 20,000 tonnes/year) are in the financing phase in the US, Scotland, and Norway.

9.2 NON-FED AQUACULTURES OF MOLLUSKS AND PLANTS

Measured by weight, about half of the world's aquaculture production of animals and plants comes from systems that do not require any external supply of feed[1]. Bivalves and seaweeds are some of the species that are produced in large quantities in such systems. Some fish species, especially carps, can also be produced in non-fed systems, but the use of feed containing fish oil is increasing[10].

From an ecosystem service point of view, non-fed systems have the advantage that they do not increase the pressure on wild forage fisheries or agricultural production of fish feed. Although it cannot be excluded that undesirable local effects of such aquacultures can occur[6], they also have obvious advantages from a eutrophication point of view. This is particularly true if the products are used directly for human consumption and not as feed to farmed fish.

Examination of the geographic distribution of the production of mollusks and seaweeds shows that it is extremely unevenly distributed over the world's marine environments. Two countries, China and Indonesia, are responsible for about 85% of the total mariculture of seaweeds, and China alone accounts for about 85% of the mariculture of mollusks. This strongly indicates that there are very large untapped resources for seaweed and mollusk production in other parts of the world. The major increase is taking place in Asia where the production and consumption of mollusks and seaweeds is already higher than on other continents.

9.3 GENERAL REMARKS

On a global level, production of food is increasingly carried out in systems that enable full control of inputs and outputs. Livestock and chicken breeding is being moved into concentrated feeding operations, and greenhouse crop production is a growing reality throughout the world. It is probable, or at least not unlikely, that a similar trend will soon appear in fish farming. RAS are of particular interest because they are not constrained by access to suitable inland or marine waters.

Whether or not an increasing production of farmed fish in RAS will be environmentally advantageous depends strongly on how RAS are integrated into a product chain that starts with production of fish feed[11] and what role farmed fish will play in the global supply of animal protein. Regarding non-fed systems for production of mollusks and seaweeds, the major challenge is the uneven geographical pattern of both production and consumption. This pattern is not only a result of natural conditions and available technologies, but also a matter of attitudes to unconventional food sources among consumers.

Considering that aquaculture is in a state of rapid growth and structural change, several groups of actors can play a key role in influencing this segment of the food sector so that both food security and environmental issues, including eutrophication, are taken into account.

10 RECOVERY OF PHOSPHORUS FROM SEWAGE SLUDGE

The description of phosphorus flows in chapter 7 showed how strongly the flow of this element is intertwined with basic human needs. Phosphorus is also a finite resource for which there are no substitutes in agriculture. The present supply is almost exclusively based on mining of phosphate rock. The global reserves of this commodity (about 70 million tonnes P_2O_5) might look reassuring compared to the current annual consumption (about 42,000 tonnes P_2O_5)[1]. However, phosphate rock is mined at just a handful of locations worldwide, primarily in China, Morocco, Western Sahara, and the US. Moreover, the largest deposits can be found in politically unstable regions, and the amount of undesirable cadmium in the rock varies between deposits. This has caused the EU to classify phosphorus as a critical raw material[2], and the interest in recycling phosphorus into crop production is increasing[3].

10.1 INCREASING QUANTITIES OF PHOSPHORUS IN SEWAGE SLUDGE

It has already been mentioned that there are two major imbalances in the current fluxes of phosphorus through society, and large amounts of phosphorus are accumulated in areas with intensive animal farming and in urban areas. In this chapter, we focus on technological solutions to recover phosphorus from sludge produced at wastewater treatment plants. Model calculations presented in an OECD report[4] indicate that there will be a dramatic increase in the phosphorus emissions from urban wastewater systems during the coming decades (see Appendix) unless heavy investments are made in phosphorus removal. This increase is due to the following three factors: (i) a dramatic increase in the world's urban population, (ii) a higher percentage of urban residents connected to wastewater systems, and (iii) dietary changes towards more animal food. On the other hand, if tertiary treatment to remove phosphorus from the wastewater is widely implemented, there will be a dramatic increase in the amount of phosphorus in sewage sludge.

10.2 RECYCLING OPTIONS FOR PHOSPHORUS IN SEWAGE SLUDGE

Direct application of sewage sludge onto agricultural soil is counteracted in many countries due to potential health risks. Untreated sludge can spread pathogens and contains undesirable materials such as heavy metals and organic micropollutants, including drug residues. In addition, direct application can be impracticable with large distances between agricultural land and the urban areas with nutrient-rich sewage. These circumstances have led to a growing interest in technical solutions in which phosphorus from sewage sludge is converted into a transportable and marketable form.

A recent review of phosphorus recovery methods identified about 50 potentially useful methods, and 19 of them were evaluated using a comprehensive evaluation scheme[5]. Available methods can be divided into the following three major groups based on different entry points in the sewage treatment process: (i) recovery from the aqueous phase of sewage, (ii) recovery from sewage sludge, and (iii) recovery from sewage sludge ash, i.e. sludge that has been incinerated.

An ideal recovery technology would achieve a high recovery rate at an acceptable cost and would result in a product practically free of harmful pollutants and with a good fertilization effect. There is presently no technology that combines all of these good features, but a large number of technologies have already been implemented at a cost of less than 5 euro per year per person connected to the sewage system[5]. Technologies to recover phosphorus from (i) the aqueous phase of sewage or (ii) sewage sludge usually result in products with low concentrations of undesirable pollutants, but the recovery of phosphorus is less than 50%. Sewage sludge ash enables a substantially higher recovery rate but can require extensive post-treatment to remove heavy metals.

Full-scale plants for phosphorus recovery from sewage sludge using enhanced biological phosphorus removal followed by crystallization of struvite are now in operation in Germany, the Netherlands, the UK, the US, and Canada. This type of recovery can be based on the AirPrex® and Ostara® technologies, and the final product can be used as fertilizer.

Sewage sludge ash is another promising material for recovery of phosphorus[6]. A pilot-scale plant in Hamburg, Germany, has been in operation since 2015, and an industrial-scale plant is under construction in Dunkerque, France. Particularly promising results have been obtained for the EcoPhos® and TetraPhos® technologies in which wet-chemical extraction of sewage sludge is integrated with conventional production of phosphoric acid.

10.3 A LONG-TERM PLAN FOR PHOSPHORUS RECOVERY IN GERMANY

Phosphorus recovery from sewage sludge has long been discussed in some European countries, and recently a new sewage sludge ordinance passed the German cabinet. Once approved by both chambers, the new sewage sludge ordinance will make phosphorus recovery from sewage sludge obligatory for all German wastewater treatment plants larger than 50,000 person equivalents (p.e.). They will have to recover the phosphorus if the sludge contains more than 2% phosphorus dry solids or will have to incinerate the sludge in mono-incinerators. The treatment plants above 100,000 p.e. will have to fulfill the new phosphorus recovery requirements by 2029, while plants of 50,000 to 100,000 p.e. will get three additional years for implementation.

10.4 GENERAL REMARKS

In recent years, several technologies have been developed and, in some cases, implemented in full scale. Even though these technologies are not yet fully profitable, the extra cost is often less than 5 euro per year per person connected to the sewage system. This opens up for regulations that will favor transitions towards a more sustainable use of phosphorus. Because a variety of technical solutions are available, the choice of solutions can be adapted to local conditions.

11 RECOMMENDATIONS

Most of the measures taken so far to reduce direct emissions and riverine inputs of pollutants into the sea can be classified as some kind of cleanup operation. Society reacts after undesirable environmental effects become obvious, and hot spots are then screened and potential technical solutions are evaluated. Policy instruments are also evaluated and, at best, they are promptly implemented to eliminate apparent examples of environmental pollution.

In numerous cases, coordinated cleanup operations have led to substantial reductions of point emissions. HELCOM has seen the input of phosphorus to the Baltic Sea decrease by approximately 50%[1], primarily due to better treatment of urban wastewaters. International river commissions, such as the International Commission for the Protection of the Rhine[2], can provide other examples of successful reduction of point source inputs of both toxic substances and nutrients into marine environments.

Diffuse emissions of water pollutants, such as leaching of nutrients from agricultural land, have so far been addressed primarily by treating them as clusters of minor point sources. Technology requirements, environmental quality standards, mandatory nutrient budgets for individual farms, and pollution caps for entire sectors constitute important categories of regulations that have proven useful to reduce diffuse emissions from agriculture. However, even in regions where considerable efforts have been made to reduce both point and nonpoint sources it has been difficult to reach the targets that have been set for the total pollution load of marine waters.

In a note on policies, actions, and strategies to address nutrient pollution, the World Resources Institute emphasizes that the drivers of eutrophication are diverse and that they include interrelated social and economic factors that ultimately lead to increasing levels of nutrient pollution. Accordingly, reduction strategies need to be comprehensive, addressing multiple sources and pathways[3].

Cleanup operations, such as the introduction of adequate wastewater treatment in urban areas, are generally a necessary first step but are not sufficient for sustainable solutions to severe eutrophication problems. This report underscores the importance of complementing cleanup operations with transformative measures that make the entire chain from food production to food consumption to handling of wastewater and solid wastes more sustainable. In the following, a set of recommendations to mitigate marine eutrophication is presented. Some of them are primarily directed to governments and national agencies. However, active participation of a multitude of stakeholders, including market actors and consumers, is a prerequisite for successful mitigation of marine eutrophication. In addition, it is emphasized that nutrients should be regarded as a valuable resource rather than an undesirable pollutant.

The recommendations listed below are directly targeted to the UN SDG about life below water, i.e. SDG 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development. In this goal, it is explicitly stated that nutrient pollution of coastal waters from land-based sources should be prevented or substantially reduced. The efforts to achieve this target are likely to be more successful if synergies and goal conflicts with other SDGs are carefully considered. Because of this, each recommendation is accompanied by a short discussion of how it is related to sustainability goals other than SDG 14.

11.1 PROMOTE ACTIVITIES THAT RAISE AWARENESS OF THE ROOT CAUSES OF EUTROPHICATION

Some of the ecological effects of marine eutrophication, especially algal blooms and fish kills, are easily visible and often reported by the media. Consequently, many people know that both coastal and offshore waters can be negatively influenced by human activities. However, this does not imply that people in general are aware of the major root causes of eutrophication, such as the connection between their own food consumption and marine eutrophication. Nor is there any evidence that professional buyers and sellers in the food sector, or persons involved in procurement of catering services, are fully aware of how their behavior can influence marine eutrophication. Tools for calculation of nutrient footprints could be helpful, as well as platforms in the form of annual conferences or mutual agreements.

Recommendations to national agencies and actors in the food sector:

- *Establish recognized platforms where professional actors from national agencies, local authorities, and the food sector are invited to identify their own role and their own responsibility to reduce eutrophication.*
- *Develop tools and platforms that can facilitate collaboration between actors in different parts of a product chain with a common goal to reduce marine eutrophication.*

These recommendations are in line with at least three of the targets in SDG 12: Responsible consumption and consumption. Many existing POMs to mitigate marine eutrophication overlook important groups of actors, such as consumers and market actors. Both this report and SDG 12 emphasize that companies, especially large and transnational companies, should be encouraged to adopt sustainable practices and to integrate sustainability information into their reporting cycle (target 12.6). It is also underscored that people everywhere should have the relevant information and awareness for sustainable development (target 12.7). Moreover, actors who well understand their role and responsibility to save the marine environment can better promote procurement practices that are sustainable (target 12.8).

11.2 ENGAGE COMMERCIAL ACTORS TO PROMOTE SUSTAINABLE DIETS

Fluxes of nitrogen and phosphorus into aquatic environments can be strongly influenced by dietary habits. Nutrients are emitted both during production of food and through discharges from sewage systems, and a high consumption of protein-rich food has emerged as one of the root causes of eutrophication. In fact, a large fraction of the global population now has an over-consumption of protein, especially animal protein. Moreover, the World Health Organization recommends a lower consumption of red and processed meat. This calls for measures that would be beneficial to both marine environments and human health.

Recommendation to governments, national agencies, and commercial actors in the food sector:

- *Take actions to make it easier for consumers to adjust their total intake of protein to levels motivated by health reasons.*

This recommendation demonstrates how mitigation of marine eutrophication can go hand in hand with efforts to achieve SDG 2 (Zero hunger), SDG 3 (Good health and well-being), SDG

13 (Climate action), and SDG 12 (Responsible consumption and production). Lower consumption of meat, especially beef and pig meat, can be motivated by health risks alone in large parts of the world. However, a lower demand for meat enables a considerable shift in land use from production of animal feed to production of food for direct human consumption. This can help to feed a growing world population without increasing emissions of greenhouse gases and losses of nutrients to aquatic environments. Because human feces and urine are normally the main sources of nutrients in sewage, and protein-rich diets are rich in nutrients, a lower intake of protein can also reduce emissions of nutrients from sewage systems.

11.3 SUPPORT NEW CONCEPTS FOR MORE EFFICIENT RECYCLING OF PLANT NUTRIENTS

Urbanization and industrialization of agriculture have created fundamental imbalances in the fluxes of nitrogen and phosphorus. Enormous amounts of nutrients are brought into urban areas with food, but only a small fraction of the phosphorus in municipal wastewater is recycled back into arable land. Due to large-scale disconnection of crop production and animal farming, enormous amounts of phosphorus also accumulate in areas with intensive livestock production. To achieve long-term solutions to recycling problems, cleanup operations need to be complemented with measures involving a substantial transformation of the food and waste sectors.

Recommendations to governments and politicians:

- *Implement mandatory processing and recycling of surplus manure in regions with intensive animal farming and support innovations in the processing of manure into valuable, transportable products.*
- *Introduce mandatory recovery of depolluted phosphorus from sewage sludge. In addition, develop an internationally harmonized quality control framework for recycling of phosphorus into agricultural soils.*

Efficient use of natural resources is one of the targets in SDG 12 (Responsible consumption and production). Because phosphorus is a finite resource that cannot be substituted in agriculture, recirculation of this element from manure to agricultural soil is a necessity. Regulations involving mandatory processing and recycling of surplus manure can help to close some gaps in the current fluxes of phosphorus, but also reduce long-term losses of phosphorus to aquatic environments by counteracting the spatial separation of crop production and animal farming. Recirculating phosphorus from sewage sludge is another necessity to achieve SDG 12, but this is a complex issue because sludge can spread undesirable pollutants. There is also a temporary goal conflict between mitigation of eutrophication and making clean water and sanitation available to all according to SDG 6. The worldwide growth of urban populations calls for massive investments in new wastewater systems to achieve SDG 6. However, emissions of nutrients from such systems, or accumulation of nutrients in sludge, will increase until the sewage systems have been equipped with adequate systems for recovery of phosphorus in depolluted forms.

11.4 SUPPORT SUSTAINABLE FORMS OF AQUACULTURE

Fish farming is the fastest growing sector in the global supply of protein-rich food. However, many of the current practices have substantial environmental drawbacks. A substantial fraction of the nutrients in commercial fish feed are lost from prevailing marine farming systems.

Moreover, farming salmon, trout, and other carnivorous fish species requires large inputs of wild fish for feed. New technologies are thus strongly needed. Land-based aquacultures in closed containments, if properly designed, can substantially reduce or eliminate some of the obvious weaknesses of open feeding systems. However, it is important how such production of farmed fish is integrated into production chains and the global protein supply. Both food security and adequate protection of marine ecosystems need to be ensured. Moreover, it is desirable that non-fed systems for production of mollusks and seaweeds increase in some regions.

Recommendations to governments and politicians:

- *Support the development of environmentally sound systems for fish production in land-based closed containments and establish or support a certification system for such production.*
- *Promote expansion of markets for mollusks and seaweeds in non-fed aquacultures.*

These recommendations are in line with SDG 2 (Zero hunger) and, in particular, the target to ensure sustainable production systems and implement resilient agricultural practices that increase productivity. Mollusks and seaweeds are underexploited global food sources. Fish production in properly designed, land-based systems can reduce marine eutrophication by providing alternatives to the currently dominating sources of animal protein. Provided that the farmed fish is primarily fed with vegetarian products, it can also satisfy an increasing demand for fish without contributing to continued overfishing.

11.4.1 ESTABLISH STRONG INSTITUTIONS WITH A MANDATE TO UNDERTAKE COORDINATED ACTIONS

The great majority of the success stories in environmental management have two factors in common – strong institutions and coordinated actions. Strong institutions are needed to provide legitimacy to actions, secure adequate funding, and ensure that agreed measures are implemented. Coordination is required in different spatial scales so that management of marine eutrophication operates on a scale that is compatible with the scale in which ecological effects are manifested. Accordingly, regional sea conventions, such as HELCOM, and source-to-sea approaches, such as the Chesapeake Bay Program, often play a key role. Because the fluxes of nitrogen and phosphorus are so intertwined with basic human needs, it is also necessary that eutrophication issues are taken into account in a variety of different contexts both within and outside environmental management. In particular, the close relationship between land use, production and consumption of food, and the preconditions for efficient mitigation of eutrophication need to be recognized.

Recommendations to governments:

- *Use regional sea conventions and watershed programs to promote cleanup operations as well as transformative measures regarding food production and consumption.*
- *Give national authorities the mandate to handle goal conflicts so that mitigation of marine eutrophication is accomplished without sacrificing food security or other SDGs.*

These recommendations are relevant not only for mitigation of marine eutrophication but also for several of the targets in SDG 17 (Partnerships for the goals). In particular, they can help to enhance policy coherence for sustainable development (target 17:14). They are also in line with the general idea that the UN SDGs should be managed and achieved together, not one by one.

11.5 CAPITALIZE ON ENVIRONMENTAL SYNERGIES

The sustainable development goals that have been established are important as separate goals but are even more important as a set of coordinated goals with substantial environmental synergies. Several of the measures proposed or implemented to reduce emissions of greenhouse gases in the agriculture and food sectors are also beneficial from a eutrophication point of view. Considering that climate actions have become widely accepted, this opens a window of opportunity to implement actions that simultaneously save the climate and reduce marine eutrophication.

Recommendation to governments and national agencies:

- *Make efficient use of climate actions that also mitigate eutrophication effects.*
- *Map out on national, regional, and global levels how actions against climate change and eutrophication facilitate or hold back the achievement of other sustainable development goals.*

The agricultural sector is the world's second-largest emitter of greenhouse gases after the energy sector, which includes emissions from power generation and transport. Methane emissions are primarily caused by cattle farming, and a considerable fraction of the nitrous oxide emissions are caused by the addition of natural or synthetic fertilizers in crop production. In addition, depletion of the carbon stocks of agricultural soils has long made a considerable contribution to the carbon dioxide concentration in the atmosphere. Almost any efforts to reduce greenhouse gas emissions from agriculture would also reduce nutrient losses to aquatic environments. Lower production and consumption of animal protein, especially red meat, has already been mentioned. Lower average fertilization rates, or fertilization rates thoroughly optimized to local conditions, constitute another option. Less tilling, or other changes in agricultural practices that would increase the carbon stock of agricultural soils, is a third option. In summation, efforts to achieve SDG 13 (Climate action) provide a unique possibility to transform the agriculture and food sector in a manner that would also reduce marine eutrophication.

12 CONCLUDING REMARKS

The current review of measures to combat marine eutrophication illustrates how different problem formulations and solutions exist in parallel. To some extent, this can be explained by varying natural conditions and the fact that different countries and regions are in different economic development phases. But even in areas that have had a high economic standard for many decades, it can take a long time before new perspectives and solutions to problems become generally accepted. This was clearly illustrated by the results of a literature search that was undertaken at an early stage of the work on the current report.

When the SCOPUS database, which is the largest database of peer-reviewed articles in scientific journals, was searched for titles and abstracts containing the words “eutrophication” and “water”, several thought-provoking patterns emerged. Articles dealing with freshwater eutrophication began to increase in numbers in the early 1970s, but the number of articles about eutrophication of marine waters did not increase markedly until the late 1980s. Thereafter, it took yet another decade until the scientific community began to pay attention to societal driving forces behind the global increase of aquatic environments suffering from nutrient over-enrichment. Some highlighted the role of urbanization and the accumulation of nutrients in urban areas[1]. Others underscored that the environmental effect of improved agricultural practices and sewage treatment technologies is reduced by several societal trends, including increasing populations, urbanization, disconnection between crop production and animal farming, over-consumption of animal food, and increasing use of phosphorus-containing food additives[2].

Today, societal driving forces behind environmental change are a common topic of scientific articles. About 20 articles each year concern eutrophication and food consumption, but the great majority of these articles are limited to technical comparisons of the nitrogen or phosphorus footprint of different products or production methods. The current review of measures to combat marine eutrophication aimed to introduce a wider perspective that also includes a systematic search for actors whose behavior can reduce the pressure on marine environments. Many decision-makers in private and public organizations, and many individual consumers, can do more than they know to influence nutrient fluxes from land into the sea. It is with great pleasure, therefore, that we, as authors of the current report, have noted that SDG 12 (Responsible consumption and production) includes a clear actor’s perspective. A key role is also played by companies, especially large and transnational companies, persons involved in public procurement, and conscious consumers.

The strong focus on the food sector in the current review is also worth some remarks. First, this sector is responsible for the largest fluxes of nutrients through society and into the sea. Second, food production and consumption, including sewage treatment, are possible to influence. New technologies can be helpful, but food consumption is also a matter of attitudes to new types of food with a sustainable ecological footprint. This implies that successful mitigation of marine eutrophication requires active engagement from a great variety of actors in society.

As argued already in the first chapter, shipping is another sector that needs to be taken into account when measures to mitigate eutrophication are considered. In the current report, measures related to shipping are only mentioned in the sections concerning the Baltic Sea and the North Sea. However, while pollution from shipping is of particular concern in these areas, there is also a global potential to reduce the nitrogen pressure from this sector. IMO has an important role here because uniform rules are necessary.

Assessment of the cost-effectiveness of different measures to mitigate eutrophication of marine environments was outside the scope of the present report. However, active engagement in measures to save the marine environment has a commercial value for many enterprises, and the new technologies mentioned in Chapters 8 and 9 are very close to being profitable. Moreover, it cannot be overemphasized that the global increase of marine eutrophication due to disrupted nutrient cycles threatens huge natural resources. The oceans constitute the world's largest source of protein, and it has been estimated that fish provides 3.1 billion people with almost 20% of their intake of animal protein[3]. Thus, if this resource is not managed effectively, it will eventually lead to extremely costly habitat restorations needs.

13 REFERENCES

REFERENCES TO CHAPTER 1

1. WRI (2017). Interactive map of eutrophication and hypoxia. World Resources Institute. Available at: http://www.wri.org/media/maps/eutrophication/fullscreen.html [Accessed 2 May 2017]

2. Vollenweider, RA. (1968). Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Technical Report DAS/CS 1/68.27. Paris: OECD.

3. Schindler, DW. (1971). Carbon, nitrogen, and phosphorus and the eutrophication of freshwater lakes. Journal of Phycology 7:321-329.

4. GLWQA (1972). Great Lakes Water Quality Agreement 1972. Available at: https://www.ec.gc.ca/grandslacs-greatlakes/default.asp?lang=En&n=E615A766-1 [Accessed: 06 Feb 2017].

5. CBP (1983). Chesapeake Bay Program. Available at: http://www.chesapeakebay.net/about [Accessed 06 Feb 2017].

6. HELCOM (1988). Declaration on the protection of the marine environment of the Baltic Sea area. HELCOM convention. Available at: http://www.helcom.fi/Documents/About%20us/Convention%20and%20commitments/Ministerial%20declarations/MinDecl1988.pdf [Accessed 02 May 2017]

7. Boynton, WR., Kemp, VM., Keefe, WM. (1982). A comparative analysis of nutrients and other factors influencing estuarine phytoplankton production, p. 69-90. In: Kennedy, VS. (Ed.) Estuarine Comparisons. New York: Academic Press.

8. Galloway, JN., Schlesinger, WH., Levy II, H., Michaels, A., Schnoor, JL. (1995). Nitrogen fixation: Anthropogenic enhancement-environmental response. Global Biogeochemical Cycles, 9:235–252.

9. Howarth, RW., Billen, G., Swaney, D. et al. (1996). Regional nitrogen budgets and riverine N & P fluxes for the drainages to the North Atlantic Ocean: natural and human influences. Biogeochemistry 35:75–139.

10. Billen, G. (2011). Nitrogen flows from European regional watersheds to coastal marine waters. In: Sutton et al. (Eds.) The European Nitrogen Assessment. Cambridge: Cambridge University Press.

11. Fowler, D. et al. (2013) The global nitrogen cycle in the twenty-first century. Philosophical Transactions of the Royal Society B 368 20130164. Available at: http://dx.doi.org/10.1098/rstb.2013.0164 [Accessed 02 May 2017]

12. Scholz, RW., Roy, AH., Brand, FS., Hellums, D., Ulrich, AE. (2014). Sustainable Phosphorus Management: A Global Transdisciplinary Roadmap. Dordrecht: Springer Science.

13. Gruber, N., Galloway, JN. (2008). An earth-system perspective of the global nitrogen cycle. Nature 451:293-296.

14. Mackenzie, FT., Ver, LM., Lerman, A. (2002). Century-scale nitrogen and phosphorus controls of the carbon cycle. Chemical Geology 190:13-32.

15. Rockström, J. et al. (2009). Planetary boundaries: exploring the safe operating space for humanity. Ecology and Society 14(2):32.

16. UNEP (2017). UN Environment. The Regional Seas Programme. Available at: http://www.unep.org/regionalseas/who-we-are/overview [Accessed 02 May 2017]

17. OSPAR (1992). OSPAR Convention. Available at: http://www.OSPAR.org/convention/text [Accessed 08 Feb 2017]

18. HELCOM (1992). HELCOM Convention. Available at: http://HELCOM.fi/about-us/convention [Accessed 08 Feb 2017]

19. Iho, A., Ribaudo, M., Hyytiäinen, K. (2015). Water protection in the Baltic Sea and the Chesapeake Bay: institutions, policies and efficiency. Marine Pollution Bulletin 93:81-93.

20. Andersen, JH. et al. (2017). Long-term temporal and spatial trends in eutrophication status of the Baltic Sea. Biological Reviews 92:135–149.

21. U.S.EPA (2015). Mississippi River Gulf of Mexico Watershed Nutrient Task Force: Reassessment 2013. U.S. Environmental Protection Agency. Available at: https://www.epa.gov/sites/production/files/2015-03/documents/hypoxia_reassessment_508.pdf [Accessed 02 May 2017]

22. OSPAR (2010). Quality status report 2010. Available at: https://www.epa.gov/sites/production/files/2015-03/documents/hypoxia_reassessment_508.pdf [Accessed 02 May 2017]

23. Sun, B., Zhang, L., Yang, L., Zhang, F., Norse, D., Zhu, Z. (2012). Agricultural non-point source pollution in China: Causes and mitigation measures. Ambio 41:370–379.

24. TWAP (2016). Large marine ecosystems – status and trends. Transboundary Waters Assessment Programme. Available at: http://www.geftwap.org/publications/lmes-technical-report [Accessed 02 May 2017]

25. Abdalla, CW. (2002). The industrialization of agriculture: Implications for public concern and environmental consequences of intensive livestock operations. Penn State Environmental Law Review 175.

26. Alexandratos, N., Bruinsma, J. (2012). World agriculture towards 2030/2050: the 2012 revision. ESA Working paper No. 12-03. Rome: FAO.

27. Strokal, M. et al. (2016). Alarming nutrient pollution of Chinese rivers as a result of agricultural transitions. Environmental Research Letters 11 (2016) 024014

28. OECD (2012). OECD Environmental Outlook to 2050: The Consequences of Inaction. Paris: OECD Publishing, Paris. doi: http://dx.doi.org/10.1787/9789264122246-en

29. OECD (2016). The Ocean Economy in 2030. Paris: OECD Publishing. doi: http://dx.doi.org/10.1787/9789264251724-en

30. Strange, T., Bayley, A. (2008). Sustainable development. Linking economy, society, environment. Paris: OECD Publishing.

31. Reay, DS. (2011). Societal choice and communicating the European Nitrogen Challenge. In: Sutton et al. (Eds.) The European Nitrogen Assessment. Cambridge: Cambridge University Press.

REFERENCES TO CHAPTER 2

1. Carstensen, J., Andersen, JH., Gustafsson, BG., Conley, DJ. (2014). Deoxygenation of the Baltic Sea during the last century. Proceedings of the National Academy of Sciences 111: 5628–5633.

2. Löwgren, M. (1988). Dynamics of Water Pollution Control, a Regional Evaluation. PhD Thesis. Linköping: Linköping Studies in Arts and Science, 26.

3. SEPA (2014). Wastewater treatment in Sweden 2014. Stockholm: Swedish Environmental Protection Agency.

4. REVAQ (2017). REVAQ Certification. Available at: http://www.svensktvatten.se/vattentjanster/avlopp-och-miljo/kretslopp-och-uppstromsarbete/revaq-certifiering/ [Accessed 07 May 2017]

5. SwAM (2017). Info om kommuner som driver på utveckling enskilda avlopp. Swedish Agency for Marine and Water Management. Available at https://www.havochvatten.se/hav/vagledning--lagar/vagledningar/sma-avlopp/goda-exempel-pa-arbete-med-kretslopp.html [Accessed 2 May 2017]. (Information regarding municipalities work to support improvements in small sewage systems)

6. Fleischer, S., Hamrin, S., Kindt, T., Rydberg, L., Stiebe, L. (1987). Coastal eutrophication in Sweden: Reducing nitrogen in land runoff. Ambio 16:246-251.

7. Rosenberg, R., Elmgren, R., Fleischer, S., Jonsson, P., Persson, G., Dahlin, H. (1990). Marine Eutrophication Case Studies in Sweden. Ambio 19:102-108.

8. SBoA (2013). Actions against plant nutrient losses from agriculture. Jönköping: Swedish Board of Agriculture.

9. Aronsson, H., Johnsson, H. (2017). Reglers betydelse för åtgärder mot jordbrukets kväve- och fosfor-förluster. Swedish University of Agricultural Sciences. ISSN 0347-9307. (The impact of regulations regarding measures against agricultural leakage of nitrogen and phosphorous.)

10. The Swedish Environmental Code (1999). Available at: http://www.government.se/legal-documents/2000/08/ds-200061/ [Accessed 2 May 2017].

11. SRDP (2017). Swedish Rural Development Programme. Available at http://www.government.se/information-material/2015/12/a-rural-development-programme-for-sweden/ [Accessed 2 May 2017].

12. SBoA (2017). Slututvärdering av landsbygdsprogrammet 2007-2013 – en sammanfattning. Report No. 2017:1. Jönköping: Swedish Board of Agriculture. (Final evaluation of the Rural Development Programme 2007-2013 – a summary).

13. HELCOM (2016). Passenger ship sewage discharges into the Baltic Sea will be banned. Available at http://www.helcom.fi/news/Pages/Passenger-ship-sewage-discharges-into-the-Baltic-Sea-will-be-banned.aspx [Accessed 2 May 2017].

14. SIME (2017). Measures to reduce impact of shipping on the marine environment. Report 2017:2. Göteborg: Swedish Institute for the Marine Environment. (Åtgärder för att minska sjöfartens påverkan på havsmiljön).

15. RBDA (2016). Vattenmyndigheternas åtgärdsprogram. River Basin District Authority. Available at http://www.vattenmyndigheterna.se/sv/nyheter/2016/pages/atgardsprogram-vatten-beslutade-2016-2021.aspx/ [Accessed 2 May 2017]. (Programmes of Measures)

16. Life IP RICH WATERS. Available at http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=6104 [Accessed 2 May 2017].

17. WWF (2017). Meat Guide. World Wide Fund for Nature. Available at http://www.wwf.se/wwfs-arbete/ekologiska-fotavtryck/kottguiden/om-kott-guiden/1595739-wwfs-kottguide-om-kottguiden [Accessed 2 May 2017].

18. SCB (2013). Nitrogen and phosphorus balances for agricultural land and agricultural sector in 2011. Statistics Sweden. Available at http://www.scb.se/Statistik/MI/MI1004/2011A01/MI1004_2011A01_SM_MI40SM1301.pdf [Accessed 2 May 2017].

19. Grimvall, A., von Brömssen, C., Lindström, G. (2014). Using process-based models to filter out natural variability in observed concentrations of nitrogen and phosphorus in river water. Environmental Monitoring and Assessment 186:5135- 5152.

20. SIME (2016). Havet 2015/ 2016. Swedish Institute for the Marine Environment. Available at http://havsmiljoinstitutet.se/digitalAssets/1575/1575894_havet_2015_16.pdf [Accessed 2 May 2017]. (The Sea 2015/2016).

21. Danish Agriculture & Food Council (2016). Danish Pig Meat Industry. Available at http://www.agricultureandfood.dk/danish-agriculture-and-food/danish-pig-meat-industry [Accessed 2 May 2017].

22. Riemann, B., Carstensen, J., Dahl, K. et al. (2016). Recovery of Danish coastal ecosystems after reductions in nutrient loading: A holistic ecosystem approach. Estuaries and Coasts 39:82-97.

23. Anker, HT. (2015). Agricultural nitrate pollution – regulatory approaches in the EU and Denmark. Nordic Environmental Law Journal. Report 2015:2.

24. DEPA (2015). Summary-Programme of Measures according to MSFD. Danish Environmental Protection Agency (2015). Available at http://ec.europa.eu/environment/marine/public-consultation/index_en.htm [Accessed 2 May 2017].

25. Andersen, JH., Carstensen, J., Conley, D.. et al. (2017). Long-term temporal and spatial trends in eutrophication status of the Baltic Sea. Biological Reviews 92:139-149.

26. HELCOM (2013). HELCOM Copenhagen Ministerial Declaration. Taking Further Action to Implement the Baltic Sea Action Plan- Reaching Good Environmental Status for a healthy Baltic Sea. Available at http://www.helcom.fi/Documents/Ministerial2013/Ministerial%20declaration/2013%20Copenhagen%20Ministerial%20Declaration%20w%20cover.pdf [Accessed 2 May 2017].

27. HELCOM (2015). Updated Fifth Baltic Sea pollution load compilation (PLC-5.5). Baltic Sea Environment Proceedings No. 145. Available at http://www.helcom.fi/Lists/Publications/BSEP145_Lowres.pdf [Accessed 2 May 2017].

28. EMEP (2016). Atmospheric Supply of Nitrogen, Cadmium, Mercury, Benzo(a)pyrene and PBDEs to the Baltic Sea in 2014. Chapter 3 - Nitrogen. MSC-W Technical Report 1/2016. Oslo, Norway: The European Monitoring and Evaluation Programme. Available at http://emep.int/publ/HELCOM/2016/Chapter3_nitrogen.pdf [Accessed 2 May 2017].

29. HELCOM (2016a). Cleaner exhaust gases from Baltic Shipping – The new NECA regulations. Available at http://helcom.fi/Lists/Publications/Baltic%20Sea%20NECA%20-%20Cleaner%20Exhaust%20Gases%20from%20Baltic%20Shipping.pdf [Accessed 2 May 2017].

30. HELCOM (2016b). HELCOM Hot Spots – Main pollution sites. Available at http://www.HELCOM.fi/action-areas/industrial-municipal-releases/HELCOM-hot-spots [Accessed 2 May 2017].

31. NEFCO (2008). Framework for a Nutrient Quota and Credits' Trading System for the Contracting Parties of HELCOM in order to reduce Eutrophication of the Baltic Sea. Helsinki, Finland: Nordic Environment Finance Corporation. Available at https://www.nefco.org/news-media/publications-reports/studyassesment/framework-nutrient-quota-and-credits-trading-system [Accessed 2 May 2017].

32. Helcom (2017). Measuring progress for the same targets in the Baltic Sea – Aligning UN Sustainable Development Goals with HELCOM regional targets and achievements. Baltic Sea Environmental Proceedings 150. Available at http://www.HELCOM.fi/Lists/Publications/BSEP150.pdf [Accessed 2 May 2017].

REFERENCES TO CHAPTER 3

1. Wageningen UR (2014). Manure – A valuable resource. Livestock research, Wageningen UR, The Netherlands. Available at: http://edepot.wur.nl/294017 [Accessed 02 May 2017]

2. Brussard, W., Grossman, MR. (1990). Legislation to abate pollution from manure: the Dutch approach. North Carolina Journal of International Law & Commercial Regulation 15(1). Available at: http://scholarship.law.unc.edu/ncilj/vol15/iss1/5 [Accessed 25 Apr 2017].

3. Schröder, JJ., Neeteson, JJ. (2008). Nutrient management regulations in The Netherlands. Geoderma 144:418-425.

4. Van Grinsven, HJM., Tiktak, A., Rougoor, CW. (2016). Evaluation of the Dutch implementation of the nitrates directive, the water framework directive and the national emission ceilings directive. NJAS – Wageningen Journal of Life Sciences 78:69-84.

5. MSFD Netherlands (2015). Marine Strategy for the Dutch part of the North Sea 2012-2020 Part 3 MSFD programme of measures. Available at: https://www.noordzeeloket.nl/en/Images/NL%20Marine%20Strategy%20part%203%20English%20translation_5022.pdf [Accessed 27 Apr 2017].

6. PARCOM (1988). Parcom recommendation 88/2 of 17 June 1988 on the reduction in inputs of nutrients to the Paris Convention area. Paris, France: Paris Commission. Available at http://www.OSPAR.org/documents?d=32444 [Accessed 2 May 2017].

7. OSPAR (2010). The North-East Atlantic Environment Strategy. Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2010–2020. OSPAR Agreement 2010-3. Available at http://www.OSPAR.org/convention/strategy [Accessed 2 May 2017].

REFERENCES TO CHAPTER 4

1. Abdalla, CW. (2002). The industrialization of agriculture: Implications for public concern and environmental consequences of intensive livestock operations. Penn State Environmental Law Review 175.

2. Breimyer, HF. (1962). The three economies of agriculture. Journal of Farm Economics 44:679-699.

3. Lanyon, L.E. (1995). Does nitrogen cycle? Changes in the spatial dynamics of nitrogen with industrial nitrogen fixation. Journal of Production Agriculture 8:70-78.

4. Kleinman, P. et al. (2012). Managing manure for sustainable livestock production in the Chesapeake Bay Watershed. Journal of Soil and Water Conservation Society 67:54A-61A.

5. Martin, LL., Zearing, KD. (1997). Relationships between industrialized agriculture and environmental consequence: The case of vertical integration in broilers and hogs. Journal of Agriculture and Applied Economics 29:45-56.

6. CBP (1983). Chesapeake Bay Program. Available at: http://www.chesapeakebay.net/about [Accessed 06 Feb 2017].

7. WRI (2013). Eutrophication&Hypoxia Map Data Set. World Resources Institute. Available at: http://www.wri.org/resources/data-sets/eutrophication-hypoxia-map-data-set [Accessed 07 May 2017]

8. U.S.EPA (2008). Gulf hypoxia action plan 2008. Mississippi River Gulf of Mexico Watershed Nutrient Task Force. U.S. Environmental Protection Agency. Available at: https://www.epa.gov/ms-htf/gulf-hypoxia-action-plan-2008 [Accessed: 07 May 2017]

9. U.S.EPA (2015). Mississippi River Gulf of Mexico Watershed Nutrient Task Force: Reassessment 2013. U.S. Environmental Protection Agency. Available at: https://www.epa.gov/sites/production/files/2015-03/documents/hypoxia_reassessment_508.pdf [Accessed 02 May 2017]

10. Maryland Department of Agriculture (2017). Agricultural Nutrient Management Program. Available at: http://mda.maryland.gov/resource_conservation/Pages/farmer_information.aspx. [Accessed: 2017-02-13]

REFERENCES TO CHAPTER 5

1. GEF TWAP (2016) Transboundary Waters Assessment Programme at the Global Environment Facility International Waters focal. Available at http://www.geftwap.org/publications/08-large-marine-ecosystems-status-and-trends/view [Accessed 2 May 2017].

2. Bristow, LA., Callbeck, CM., Larsen, M., Altabet, MA., et al. (2017). N_2 production rates limited by nitrite availability in the Bay of Bengal oxygen minimum zone. Nature Geoscience. 10: 24–29.

3. BOBLME 2015 (a). Strategic Action Programme. Bay of Bengal Large Marine Ecosystem Project. Available at http://www.boblme.org/BOBLME_SAP.html [Accessed 2 May 2017].

4. Banglapedia (2017). Green revolution. Available at http://en.banglapedia.org/index.php?title=Green_Revolution [Accessed 2 May 2017].

5. BOBLME 2015 (b). Nutrient loading eutrophication of coastal water of the South Asian Seas- a scoping study. BOBLME-2015_Ecology-02. Bay of Bengal Large Marine Ecosystem Project. Available at www.boblme.orgftwap.org/publications/08-large-marine-ecosystems-status-and-trends/view [Accessed 2 May 2017].

6. Loni, H., Bremer, S. (2013). An organic Future for Bangladeshi Shrimp? World Aquaculture 44:28.

7. Barua, PHZ., Choudhury, MSN. (2011). Nutrient mass balance for improved traditional coastal ship pond of Bangladesh. Mesopotamian Journal of Marine Science 26:98-113.

8. DFID (2005). Decentralised domestic wastewater and faecal sludge management in Bangladesh. England: Department for International Development. Available at https://assets.publishing.service.gov.uk/media/57a08c9f40f0b64974001324/R8056-Bangladesh_Case_Study.pdf [Accessed 2 May 2017].

9. Dwived, SN. (1993). Long term variability in the food chains, biomass yield and oceanography of the Bay of Bengal ecosystem. In: Sherman, K., Alexander, LM. and Gold, BD. (Eds.). Large Marine Ecosystems; Stress Mitigation and Sustainability, p 43-52. AAAS Press, Washington D.C.

10. Aquaculture Authority (2002). Shrimp aquaculture and the environment – an environmental impact assessment report. Aquaculture Authority, Chennai, India. Aquaculture Authority News. Available at http://www.caa.gov.in/uploaded/doc/Aqua%20news%20pdf.pdf [Accessed 2 May 2017].

11. Kutty, MN. (2005). Towards sustainable freshwater prawn aquaculture – lessons from shrimp farming, with special reference to India. Aquaculture Research 36: 255-263.

12. Rajitha, K., Mukherjee, CK. Vinu Chandran, R. (2006). Application of remote sensing and GIS for sustainable management of shrimp culture in India. Aquacultural Engineering 36:1-17.

13. Putheti, RR., Okigbo, RN. Madhusoodan sai, A. Leburu, R. (2008). Ground water pollution due to aquaculture in east coast region of Nellore district, Andhra Pradesh, India. African Journal of Environmental Science and Technology 2:46-50. Available at http://www.academicjounals.org/AJest [Accessed 2 May 2017].

14. CPCB (2009). Status of water supply, wastewater generation and treatment in Class-1 cities & Class-II towns of India. Central Pollution Control Board. Control of Urban Pollution Series: CUPS/70/2009-10. Available at http://cpcb.nic.in/upload/NewItems/NewItem_153_Foreword.pdf [Accessed 2 May 2017].

15. Kamyotra, JS. Bhardwaj, RM. (2011). Municipal Wastewater Management in India. In: India Infrastructure Report 2011. International Development Finance Club. Oxford University press. Available at https://www.idfc.com/pdf/report/2011/Chp-20-Municipal-Wastewater-Management-In-India.pdf [Accessed 2 May 2017].

16. Anon (2011). 71-City water Excreta survey, 2005-2006, Centre for Science and Environment, New Delhi. Available at http://www.cseindia.org/userfiles/kolkata_chapter.pdf [Accessed 2 May 2017].

REFERENCES TO CHAPTER 6

1. UNEP (2005). Global International Waters Assessment, Regional assessment 36 East China Sea. United Nations Environment Programme.

2. Gapminder (2017). Gapminder tools. Available at: http://www.gapminder.org/tools/#_locale_id=en;&chart-type=bubbles [Accessed 03 May 2017]

3. Xu, Z., Zhang, X., Xie, J., Yuan, G., Tang, X., Sun, X., Yu, G. (2014). Total Nitrogen Concentrations in Surface Water of Typical Agro- and Forest Ecosystems in China, 2004-2009. PLoS ONE 9(3) e92850. http://doi.org/10.1371/journal.pone.0092850

4. Xie, J., Zhang, X., Xu, Z., Yuan, G., Tang, X., Sun, X., Ballantine, D. (2014). Total phosphorus concentrations in surface water of typical agro-and forest ecosystems in China, 2004–2010. Frontiers of Environmental Sciences & Engineering 8:561–569.

5. Li, M., Xu, K., Watanabe, M., Chen, Z. (2007). Long-term variations in dissolved silicate, nitrogen and phosphorus flux from the Yangtze River into the East China Sea and impacts on estuarine ecosystem. *Estuarine, Coastal and Shelf Science* 71:3-12.

6. Tong, Y. et al. (2015). Nutrient loads flowing into coastal waters from the main rivers of China (2006-2012). Nature Scientific Reports 5:15678 doi: 10.1038/srep16678.

7. Cui, S. et al. (2013). Centennial-scale analysis of the creation and fate of reactive nitrogen in China (1910-2010). Proceedings of the National Academy of Sciences 110:2052–2057.

8. Strokal, M. et al. (2014). Increasing eutrophication in the coastal seas of China from 1970 to 2050. Marine Pollution Bulletin 85:123-140.

9. Li, HM., Tang, HJ., Shi, XY., Zhang, CS., Wang, XL. (2014). Increased nutrient loads from the Chiangjiang (Yangtse) River have led to increased harmful algal blooms. Harmful Algae 39:92-101.

10. Sun, B. et al. (2012). Agricultural non-point source pollution in China: Causes and mitigation measures. Ambio 41:370–379.

11. Hou, Y. et al. (2013). The driving forces for nitrogen and phosphorus flows in the food chain of China, 1980 to 2010. Journal of Environmental Quality 42:962-971.

12. Bouwman, L. et al. (2013). Mariculture: significant and expanding cause of coastal nutrient enrichment. Environmental Research Letters 8:0044026

13. Zhang, Y., Bleeker, A., Liu, J. (2015). Nutrient discharge from China's aquaculture industry and associated environmental impacts. Environmental Research Letters 10:0045002

14. FAOstat (2017). Food and agriculture data. Food and Agriculture Organization of the United Nations. Available at: http://www.fao.org/faostat/en/#home [Accessed 03 May 2017]

15. Smith, R., Mingxin, X. (2015). CAFOs in the US and China: a comparison of the laws that protect water quality from factory farming, Technical Report, Vermont Law School.

16. Ma, L. et al. (2012). Nitrogen and phosphorus use efficiencies and losses in the food chain in China at regional scales in 1980 and 2005. Science of the Total Environment 434:51-61.

17. Ma, L. et al. (2010). Modelling nutrient flows in the food chain of China. Journal of Environmental Quality 39:1279-1289.

18. Wang, M., Ma, L., Strokal, M., Chu, Y., Kroeze, C. (2017). Exploring nutrient management options to increase nitrogen and phosphorus use efficiencies in food production of China. Agricultural Systems. Available at: http://dx.doi.org/10.1016/j.agsy.2017.01.001

19. Strokal, M. et al. (2016). Alarming nutrient pollution of Chinese rivers as a result of agricultural transitions. Environmental Research Letters 11(2).

20. Jin, L., Zhang, G., Tian, H. (2014). Current state of sewage treatment in China. Water Research 66:85-98.

21. Zhang, QH. et al. (2016). Current status of urban wastewater treatment plants in China. Environment International 92-93:11-22.

22. Yang, G., Zhang, G., Wang, H. (2015). Current state of sludge production, management, treatment and disposal in China. Water Research 78:60-73.

REFERENCES TO CHAPTER 7

1. Sundblad, E.-L., Vallin, A., Grimvall, A., Emmerson, R. (2015). Samhällsfenomen och åtgärder mot övergödningen. Report 2015: 6. Havsmiljöinstitutet, Sverige. (Societal phenomena and measures against eutrophication. Swedish Institute for the Marine Environment).
2. Linderholm, K., Mattsson, J-E. (2013). Analys av fosforflöden i Sverige. Report No. 2013:5. Alnarp: Swedish University of Agricultural Sciences. (Analysis of phosphorus fluxes in Sweden)
3. Ejhed, H. et al. (2011). Beräkning av kväve- och fosforbelastning på vatten och hav för uppföljning av miljökvalitetsmålet "Ingen övergödning". Report No. 56. Svenska MiljöEmissionsData (SMED).
4. Ejhed, H. et al. (2014). Beräkning av kväve- och fosforbelastning på havet år 2011 för uppföljning av miljökvalitetsmålet "Ingen övergödning". Report No. 154. Svenska MiljöEmissionsData (SMED).
5. Wallin, A., Zannakis, M., Johansson, L-O., Molander, S. (2013). Influence of interventions and internal motivation on Swedish homeowners' change of on-site sewage systems. Resources, Conservation and Recycling 76:27-40.
6. Focus on nutrients (2017). Greppa näringen. Available at: http://www.greppa.nu/om-greppa/om-projektet/in-english.html [Accessed 03 May 2017]

REFERENCES TO CHAPTER 8

1. Vallin, A., Grimvall, A, Sundblad, E-L., Djodjic, F. (2016). Changes in four societal drivers and their potential to reduce Swedish nutrient inputs into the sea. Gothenburg: Swedish Agency for Marine and Water Management. Report 2016:11. Available at https://www.havochvatten.se/download/18.44ebc86154b1fe664acd0ea/1464031299115/rapport-2016-11-changes-in-four-societal-drivers-and-their-potential-to-reduce-swedish-nutrient-inputs-into-the-sea.pdf [Accessed 2 May 2017].
2. SBoA (2011 a). Marknadsöversikt fågelkött och ägg. Report No. 2011.31 Jönköping: Swedish Board of Agriculture. Available at http://www2.jordbruksverket.se/webdav/files/SJV/trycksaker/Pdf_rapporter/ra11_31.pdf [Accessed 2 May 2017].
3. SBoA (2011 b). Marknadsöversikt griskött. Report No. 2011.41 Jönköping: Swedish Board of Agriculture. Available at http://www2.jordbruksverket.se/webdav/files/SJV/trycksaker/Pdf_rapporter/ra11_41.pdf [Accessed 2 May 2017].
4. SBoA (2011 c). Marknadsöversikt-nöt- och kalvkött. Report No. 2011.32 Jönköping: Swedish Board of Agriculture. Available at http://www2.jordbruksverket.se/webdav/files/SJV/trycksaker/Pdf_rapporter/ra11_32.pdf [Accessed 2 May 2017].
5. WHO (2007). Protein and Amino Acid Requirements in Human Nutrition. WHO technical report series 935 (ed FAO/UNU). World Health Organization, Geneva.

6. SBoA (2017). Statistical database as regards the agricultural sector and aquaculture. Swedish Board of Agriculture. Available at http://www.statistikdatabasen.scb.se/pxweb/en/ssd/?rxid=efc3e119-2e4e-4068-9725-bb9b0cf35692 [Accessed 2 May 2017].

7. National Food Agency (2012). Riksmaten – vuxna 2010–11: vad äter svenskarna? Livsmedels- och näringsintag bland vuxna i Sverige. Uppsala, Sweden. Available at https://www.livsmedelsverket.se/matvanor-halsa--miljo/kostrad-och-matvanor/matvanor---undersokningar/riksmaten-2010-11---vuxna [Accessed 2 May 2017].

8. Hallström, E., Röös, E., Börjesson, P. (2014). Sustainable meat consumption: a quantitative analysis of nutritional intake, greenhouse gas emissions and land use from a Swedish perspective. Food Policy 47:81-90.

REFERENCES TO CHAPTER 9

1. FAO (2016). The State of World Fisheries and Aquaculture 2016. Contributing to food security and nutrition for all. Rome: FAO.

2. Hasan, MR., New, MB., (Eds.) (2013). On-farm feeding and feed management in aquaculture. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome: FAO.

3. Wang, X. et al. (2013). Chemical composition and release rate of waste discharge from an Atlantic salmon farm with an evaluation of IMTA feasibility. Aquaculture Environment Interactions 4:147-162.

4. Zhang, Y., Bleeker, A., Liu, J. (2015). Nutrient discharge from China's aquaculture industry and associated environmental impacts. Environmental Research Letters 10:0045002.

5. Bouwman, L. et al. (2013). Mariculture: significant and expanding cause of coastal nutrient enrichment. Environmental Research Letters 8:044026.

6. Heisler, J. et al. (2008). Eutrophication and harmful algal blooms: A scientific consensus. Harmful Algae 8:3-13,.

7. Davidson, J. et al. (2015). Production of market-size North American strain Atlantic salmon *Salmo salar* in a land-based recirculation aquaculture system using freshwater. Aquacultural Engineering 74:1–16.

8. Liu, Y. et al. (2016). Comparative economic performance and carbon footprint of two farming models for producing Atlantic salmon (*Salmo salar*): Land-based closed containment system in freshwater and open net pen in seawater. *Aquaculture Engineering* March 2016, pp. 1-12.

9. DNB (2017). Seafood special report. Deep dive into land-based farming. Research report prepared by DNB Markets, a division of DNB Bank ASA, Norway.

10. Chiu, A., Li, L., Guo, S., Bai, J., Fedor, C., Naylor, RL. (2013). Feed and fishmeal use in the production of carp and tilapia in China. Aquaculture 414-415:127-134.

11. Troell, M. et al. (2014). Does aquaculture add resilience to the global food system? Proceedings of the National Academy of Sciences 111:13257–13263.

REFERENCES TO CHAPTER 10

1. USGS (2016). Mineral commodity summaries 2016. U.S. Geological Survey.

2. European Commission (2014). Communication from the Commission to the European Parliament, the Council, the European economic and social Committee and the Committee of the regions (On the review of the list of critical raw materials for the EU and the implementation of the Raw Materials Initiative).

3. European Commission (2013). In depth report: Sustainable use of phosphorus. Oct 2013, Issue 7.

4. OECD (2012). OECD Environmental Outlook to 2050: The Consequences of Inaction, OECD Publishing, Paris. doi: http://dx.doi.org/10.1787/9789264122246-en

5. Egle, L., Rechberger, H., Krampe, J., Zessner, M. (2016). Phosphorus recovery from municipal wastewater: An integrated comparative technological, environmental and economic assessment of P recovery technologies. Science of the Total Environment 571:522-542.

6. Herzel, H., Krüger, O., Hermann, L., Adam, C. (2015). Sewage sludge ash - A promising secondary phosphorus source for fertilizer production. Science of the Total Environment 542:1136–1143 (Part B).

REFERENCES TO CHAPTER 11

1. HELCOM (2013). Baltic Sea is on its way to recovery. Available at: http://www.helcom.fi/Lists/Publications/Baltic%20Sea%20is%20on%20its%20way%20to%20recovery.pdf [Accessed 08 May 2017]

2. ICPR (2017). International Commission for the Protection of the Rhine. Available at: http://www.iksr.org/en/index.html [Accessed 07 May 2017]

3. Selman, M., Greenhalgh, S. (2009). Eutrophication: Policies, Actions, and Strategies to Address Nutrient Pollution. WRI Policy Note. World Resources Institute. Available at: http://www.wri.org/publication/eutrophication-0 [Accessed 07 May 2017]

REFERENCES TO CHAPTER 12

1. Folke, C., Jansson, Å., Larsson, J., Costanza, R. (1997). Ecosystem appropriation by cities. Ambio 26:167-172.

2. Forsberg, C. (1998). Which policies can stop large-scale eutrophication? Water Science and Technology 37:193-200.

3. FAO (2016). The State of World Fisheries and Aquaculture 2016. Contributing to food security and nutrition for all. Rome: FAO.

MAP REFERENCES

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Page 36: http://www.d-maps.com/carte.php?num_car=1690&lang=en

Page 36: https://www.epa.gov/ms-htf/mississippiatchafalaya-river-basin-marb

Page 37: http://www.chesapeakebay.net/discover/baywatershed

Page 40: http://www.d-maps.com/carte.php?num_car=3254&lang=en

Page 45: http://www.d-maps.com/carte.php?num_car=76&lang=en

Page 45: http://wwf.panda.org/about_our_earth/about_freshwater/freshwater_problems/river_decline/10_rivers_risk/yangtze/

APPENDIX

POPULATION IN SEVEN COUNTRIES (SOURCE: FAOSTAT)

Table 1. Total population in seven countries (1000 persons).

Country	1990	1995	2000	2005	2010	2015
Bangladesh	107 386	119 870	132 383	143 136	151 125	160 411
China	1 191 815	1 265 230	1 309 632	1 348 270	1 390 551	1 432 912
Denmark	5 140	5 233	5 338	5 417	5 551	5 662
India	868 890	955 804	1 042 262	1 127 144	1 205 625	1 282 390
Netherlands	14 890	15 420	15 860	16 303	16 615	16 844
Sweden	8 559	8 827	8 872	9 030	9 382	9 694
USA	254 507	268 040	284 595	298 166	312 248	325 128

Table 2. Rural population in seven countries (1000 persons).

Country	1990	1995	2000	2005	2010	2015
Bangladesh	86 111	93 866	101 153	104 762	105 090	105 427
China	864 115	861 065	827 656	763 957	696 294	627 525
Denmark	779	786	795	766	733	698
India	646 911	701 490	753 897	797 627	832 723	862 451
Netherlands	4 663	4 193	3 680	2 832	2 150	1 601
Sweden	1 446	1 428	1 417	1 416	1 402	1 375
USA	62 862	60 960	59 602	59 847	60 038	59 767

Table 3. Urban population in seven countries (1000 persons).

Country	1990	1995	2000	2005	2010	2015
Bangladesh	21 275	26 004	31 230	38 374	46 035	54 984
China	327 700	404 165	481 976	584 313	694 257	805 387
Denmark	4 361	4 447	4 543	4 651	4 818	4 964
India	221 979	254 314	288 365	329 517	372 902	419 939
Netherlands	10 227	11 227	12 180	13 471	14 465	15 243
Sweden	7 113	7 399	7 455	7 614	7 980	8 319
USA	191 645	207 080	224 993	238 319	252 210	265 361

Table 4. Percentage urban population in seven countries.

Country	1990	1995	2000	2005	2010	2015
Bangladesh	20	22	24	27	30	34
China	27	32	37	43	50	56
Denmark	85	85	85	86	87	88
India	26	27	28	29	31	33
Netherlands	69	73	77	83	87	90
Sweden	83	84	84	84	85	86
USA	75	77	79	80	81	82

PROTEIN SUPPLY IN SEVEN COUNTRIES (SOURCE: FAOSTAT)

Table 5. Average protein supply (g/capita/day)

Country	1990-1992	1994-1996	1999-2001	2004-2006	2009-2011
Bangladesh	45	44	49	52	55
China	65	76	83	87	94
Denmark	105	106	104	111	107
India	55	56	57	55	59
Netherlands	98	107	107	106	108
Sweden	96	98	103	108	108
USA	109	112	114	115	110

Table 6. Average supply of protein of animal origin (g/capita/day)

Country	1990-1992	1994-1996	1999-2001	2004-2006	2009-2011
Bangladesh	5	6	7	8	10
China	15	22	27	32	37
Denmark	70	69	65	72	67
India	9	9	10	10	12
Netherlands	66	73	75	73	73
Sweden	64	65	68	72	71
USA	70	72	73	75	71

NITROGEN FERTILIZATION RATE IN SEVEN COUNTRIES (SOURCE: FAOSTAT)

Table 7. Nitrogen fertilization rate (kg N/ha arable land)

Country	2002	2004	2006	2008	2010	2012	2014
Bangladesh	131	117	139	165	150	147	160
China	219	235	251	262	275	289	292
Denmark	70	80	81	91	74	73	73
India	65	73	87	94	105	108	108
Netherlands	319	267	269	217	213	228	211
Sweden	69	67	60	71	64	57	70
USA	63	68	72	69	71	83	80

NUTRIENT EFFLUENTS FROM WASTEWATER: BASELINE, 1970-2050 (SOURCE: OECD)

Table 8. Nitrogen emissions (million tonnes N per year)

Region	1970	2000	2030	2050
N America	0.686	0.963	1.284	1.332
Europe	1.353	1.336	1.582	1.575
Japan and Korea	0.192	0.416	0.448	0.380
Oceania	0.070	0.086	0.105	0.101
Brazil	0.045	0.328	0.679	0.689
Russia	0.371	0.388	0.388	0.338
India	0.073	0.403	1.925	3.065
China	0.130	0.894	3.246	3.690
Indonesia	0.074	0.162	0.497	0.755
Southern Africa	0.051	0.113	0.377	0.633
Middle East	0.069	0.230	0.536	0.624
Ukraine and Central Asia	0.133	0.147	0.212	0.213
Rest Latin America	0.206	0.497	1.030	1.202
Rest of SE Asia	0.017	0.080	0.581	0.885
Rest of Africa	0.091	0.323	1.352	2.438

Source: OECD (2012), OECD Environmental Outlook to 2050: The Consequences of Inaction, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/9789264122246-en

Table 9. Phosphorus emissions (million tonnes P per year)

Region	1970	2000	2030	2050
N America	0.166	0.170	0.216	0.219
Europe	0.338	0.245	0.274	0.250
Japan and Korea	0.051	0.085	0.079	0.063
Oceania	0.019	0.017	0.017	0.016
Brazil	0.010	0.070	0.166	0.138
Russia	0.078	0.075	0.084	0.065
India	0.016	0.087	0.364	0.571
China	0.030	0.190	0.650	0.766
Indonesia	0.017	0.030	0.102	0.162
Southern Africa	0.011	0.024	0.087	0.131
Middle East	0.015	0.048	0.103	0.113
Ukraine and Central Asia	0.028	0.029	0.040	0.040
Rest Latin America	0.045	0.106	0.222	0.256
Rest of SE Asia	0.004	0.017	0.128	0.208
Rest of Africa	0.020	0.069	0.283	0.494

Source: OECD (2012), OECD Environmental Outlook to 2050: The Consequences of Inaction, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/9789264122246-en

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