Chapter 20. Coastal, Riverine and Atmospheric Inputs from Land

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1. Introduction

The movement of materials from land to sea is an inevitable part of the hydrological cycle and of all geological processes. Nevertheless, human activities have both concentrated and increased these flows as a result of the creation of large human settlements, the development of industrial processes and the intensification of agriculture. Until the 1960s, many took the view that the oceans were capable of assimilating everything that humans wanted to discharge into the oceans. In the 1960s, this view came to be seen as out-dated (UNESCO, 1968). Following the 1972 Stockholm Conference on the Human Environment, many steps were taken to address issues of marine pollution. During the preparations for the United Nations Conference on Environment and Development ("the first Earth Summit"), held in Rio de Janeiro, Brazil, in 1992, there was general agreement that, in spite of what had been done, a major initiative was needed to address the problems of land-based inputs to the oceans. As a result, Agenda 21 (the non-binding action plan from the 1992 Earth Summit) invited the United Nations Environment Programme ("UNEP") to convene an intergovernmental meeting on protection of the marine environment from land-based activities (Agenda 21, 1992). In October 1995, the Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA) was adopted in Washington, DC. First among the priorities of this Programme was improving the management of waste-water: this concerned not only waste-water containing human wastes, but also waste-water from industrial processes. In addition, a wide range of other source categories also creating problems for the marine environment was identified (UNEP, 1995). The Programme reflected the experience of over twenty years' work by governments, both individually and through regional seas organizations, to address these problems. Subsequent intergovernmental reviews of the implementation of the GPA show that progress is being made in many parts of the world, but only slowly.

In evaluating the impacts of contamination on the marine environment, there are significant difficulties in comparing the situations in different areas. For many aspects of contamination, evaluating the levels of contamination requires chemical analysis of the amounts of the contaminants in samples of water, biota and/or sediments. Unless there is careful control of the sampling methods and analytical techniques in all the cases to be compared, it is difficult to achieve scientifically and statistically valid comparisons. Lack of clear and practical comparisons creates problems in setting priorities. For example, a fairly recent review of available evidence in the Wider Caribbean concluded that, among the 30 pollution studies examined, analyses varied in terms of sampling schemes, parameters and analytical techniques, and data were presented in ways which made comparison all but impossible – whether data were in terms of dry weight or wet weight, what sediment fraction was analyzed, and whether data were presented in absolute terms or as a percentage of lipids (Fernandez et al., 2007). Such differences make meaningful comparisons of the available data very difficult. For this reason, this chapter does not attempt to give detailed figures on concentrations of contaminants. The Global Environment Facility is supporting the Transboundary Waters Assessment Programme (TWAP), to enable priorities between different areas to be established.

The main issues relating to inputs to the oceans and seas from land-based sources can be categorized for the purposes of this chapter under the headings of: hazardous substances (including the effects of desalinization plants), endocrine disruptors, oil, nutrients and waterborne pathogens, and radioactive substances.

In all cases, consideration has to be given to the variety of means by which the movement of the substances from land to water takes place. The main distinction is between waterborne and airborne inputs. Waterborne inputs can either be direct (through a pipeline from the source directly into the sea, by run-off from land directly into the sea or by seepage of groundwater directly into the sea) or riverine (through runoff or leaching from land to a watercourse or by a direct discharge into a watercourse, and the subsequent flow from such watercourses into the sea). Waterborne inputs are much more readily measured, and for that reason have so far attracted more attention. There is increasing evidence that airborne inputs are more significant than has hitherto been thought, not only for heavy metals and other hazardous substances but also for nitrogen (GESAMP, 2009; Duce et al., 2008).

2. Hazardous Substances

2.1 Which substances are hazardous?

A wide range of substances can adversely affect marine ecosystems and people. The adverse effects can range from straightforward fatal poisoning to inducing cancers, weakening immune systems so that diseases develop more easily, reducing reproductive performance and inducing mutations in offspring. A first requirement for controlling the input of hazardous substances into the marine environment, whether from point or diffuse sources or through the atmosphere is therefore to establish what substances show sufficient grounds for concern that regulatory action is needed. Lists of substances identified as hazardous can never be closed: new substances are constantly being developed, and new uses are likewise constantly being found for a wide range of elements and compounds.

International effort to define substances hazardous to the marine environment began in relation to dumping of waste at sea (see Chapter 24). In this context, the Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft of 15 February 1972 (Oslo Convention) and the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter of 13 November 1972 (London Convention) established the first internationally agreed lists of substances whose introduction into the marine environment should be controlled. In both Conventions, a ban on dumping was agreed for similar "black lists". These included, among other items, substances such as toxic organohalogen compounds, agreed carcinogenic substances and mercury and cadmium and their compounds. Controls were agreed on dumping for similar "grey lists", which included, among other items, arsenic, lead, copper and zinc and their compounds, organosilicon compounds, cyanides, fluorides and pesticides not in the "black list" (Oslo Convention 1972; IMO, 1972). When attention was thereafter given to dealing with discharges and emissions from land, these "black" and "grey" lists were adapted and used by many national and international authorities concerned with the marine environment for the initial work in the field of regulation of land-based inputs of hazardous substances.

Over the past 40 years, regulatory authorities have added further categories to be controlled. In 1976 the United States Environment Protection Agency produced a list of "toxic pollutants" and an explanatory list of "priority pollutants" (EPA, 1976; EPA, 2003). An important contribution to the more general debate on the approach to control of hazardous substances was made in 1993, when the Great Lakes Commission proposed the virtual elimination of discharges of substances which are toxic and persistent (IJC, 1993). The most extensive exercise that has focused specifically on the marine environment was undertaken from 1998 by the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic to implement its long-term strategy of eliminating discharges, emissions and losses of hazardous substances which could reach and affect the marine environment. For this purpose, "hazardous substances" were defined as substances that are toxic, persistent and liable to bioaccumulate (bioaccumulation occurs when a substance taken in by an organism is not excreted, but builds up in the organism), or which give rise to an equivalent level of concern (OSPAR, 1998). This required a definition of thresholds of toxicity, persistence and bioaccumulativity. These agreed levels were applied to the more than 11,000 substances listed in the Nordic Substances Database with experimental data. The resulting list of substances of possible concern was then analysed in 2001-2004 to see which substances were only found as intermediates in closed systems, or were not being produced or used, and were therefore unlikely to affect marine ecosystems. After these had been discounted, the resulting list of chemicals for priority action was used to see what action was needed to meet the cessation target (OSPAR, 2010). The European Union, through its Regulation, Evaluation, Authorization and Restriction of Chemicals (REACH) Regulation (EU, 2006), is addressing all "persistent, bioaccumulative and toxic" (PBT) and "very persistent and very bioaccumulative" (vPvB) substances that are in substantial (more than 1 ton/year) use in its area, or proposed to be introduced. China has developed its Catalogue of Toxic Chemicals Prohibited or Strictly Controlled (China, 2014). Other organizations, such as the Arctic Monitoring and Assessment Programme, have developed similar lists (Macdonald et al., 1996).

Although there is substantial overlap between the various lists of substances where action is considered to be needed to protect the marine environment, there are variations. These result from differences in evaluation of the level of risk. Different methods of evaluation, and different choices of cut-off levels for toxicity, persistence and bioaccumulativity can lead to differing views. Different judgements are made on the extent to which precautions by users can sufficiently guard against the risks to the environment. Different views are taken on the reasonable practicability of the use of acceptable substitutes: what is regarded in some jurisdictions as acceptable (because, for example, its use can be managed acceptably) is regarded in others as unacceptable. Sometimes (as with chlordane) international action can help change what is regarded as reasonably practical. The result is that there is no single agreed list of hazardous substances that are of concern: substances that are regarded as acceptable in one area are banned in another.

Table 1 shows the principal substances which the range of authorities mentioned in the previous paragraph have regarded as hazardous to the marine environment, and on which action is being taken in all or some parts of the world to control inputs of them to the sea from land.

Table 1. Background information on substances classified by the authorities mentioned in the text as presenting hazardous characteristics and therefore justifying action.

SUBSTANCES	SOURCES AND MAIN USES[1]	PRODUCTION AND RELATED DEVELOPMENTS
† = Persistent Organic Pollutant (POP) under the Stockholm Convention on Persistent Organic Pollutants 2001; *†? = Substance under consideration for listing as a POP) under the Stockholm Convention*	** = diffuse sources, where the pathways will be mainly from leaching (especially from land-fill waste disposal), emissions to air and/or runoff*	
Heavy metals		
Cadmium	Large combustion plants; electro-plating; incinerators; paints*; batteries*	World production of cadmium is fairly stable (around 20,000 tons/year) between 2001 and 2011[2]
Copper	Mining; electric wiring and machinery*; pesticides*	World production of copper increased 15% to 16.2 million tons/year during 2001-2011[2]
Lead and organic lead compounds	Roofing*; fuel for internal combustion engines*; paint*; PVC stabilizer*	The phasing out of lead in vehicle fuel has significantly reduced inputs of lead to the seas. Emissions in Europe have decreased by 92% during 1990-2003, with similar decreases in North America[3]. World production of lead has, however, risen 53% to 4.75 million tons/year during 2001-2011[2]. Over half of this is in Australia and China.
Mercury and organic mercury compounds	Large combustion plants; electrolysis chlor-alkali plants; primitive gold-refining*	World production of mercury is relatively stable, fluctuating between 1,120 and 2,280 tons/year during 2001-2011[2]. A substantial stock-pile is, however, emerging as mercury-cell chlor-alkali plants change technology. A global Convention was adopted at Minamata, Japan, in 2013 to control trade in, and the use of, and plants discharging or emitting it. The Convention is not yet in force.
Zinc	Large combustion plants; surface-treatment of sheet metal*; cosmetics*	World production of zinc has risen by 38 % to 12.6 million tons during 2001-2011, over half in Australia, China and Peru.
Organohalogens		
Brominated diphenyls (BDPs) (hexa-BDP†) and BDP ethers (BDEs)(tetra-BDE†, penta-BDE†, hexa-BDE†, hepta-BDE and deca-BDEs)	Fire retardants in automobiles; plastics and textiles*	World production is about 40,000 tons/year. All BDEs are now controlled in a number of countries. Production and use of hexa-BDP and tetra-, penta-, hexa- and hepta-BDEs are to be eliminated under the Stockholm Convention[4].
Hexabromobiphenyl†,	Fire retardant*	No current production or use is known.
Hexabromocyclododecane	Fire retardant in plastic foam*	At its peak in the 1970s, production was about

[1] http://chm.pops.int/TheConvention/ThePOPs/tabid/673/Default.aspx and associated risk assessments, together with the relevant OSPAR Background Papers (http://www.ospar.org/content/content.asp?menu=00200304000000_000000_000000)

[2] British Geological Survey, *World Minerals Statistics Archive* (http://www.bgs.ac.uk/mineralsuk/statistics/wms.cfc?method=searchWMS

[3] United Nations Environment Programme, Final review of scientific information on lead, Nairobi, 2010.

[4] Stockholm Convention on Persistent Organic Pollutants, United Nations *Treaty Series*, vol. 2256, No. 40214.

SUBSTANCES	SOURCES AND MAIN USES[1]	PRODUCTION AND RELATED DEVELOPMENTS
(HBCDD) †?		6,000 tons /year. No production is now reported.
Hexachlorobutadiene†?	Fumigant*; transformer, hydraulic or heat transfer liquid*; viticulture pesticide*	Production and use have ceased in Europe.
Perfluorooctanyl sulphonic acid and its salts (PFOS)† and perfluorooctanesulfonyl fluoride (POSF-F)†	Electronic components*; fire-fighting foams*; insecticide*; stain repellent for carpets*; fat repellent in food-packaging	Production and use to be eliminated under Stockholm Convention, subject to specific exemptions.
Polychlorinated biphenyls (PCBs)†	Heat exchange fluids*; electric transformers and capacitors*; paint additives*; carbonless copy paper*; plastics*	Production and use to be eliminated under the Stockholm Convention. Such a prohibition has been in force since about 1990 in many States, but residues often remain.
Polychlorinated dibenzodioxins (PCDDs)† and polychlorinated dibenzofurans (PCDFs)†	Incomplete combustion of material containing organic substances and chlorine; emissions from polyvinyl-chloride (PVC) plants.	Emissions to be minimised under the Stockholm Convention
Polychlorinated naphthalenes†?	Wood preservatives*, additives to paints and engine oils*, cable insulation*; in capacitors*	
Short chained chlorinated paraffins (SCCPs)†?	Lubricants in metal working; leather treatment; production of rubber and plastics	SCCPs are produced in Brazil, China, India, Japan, Russia, Slovakia and the United States. Use in Europe and North America has dropped by about 75% since peaks in the 1990s.
Vinyl chloride	Mainly used in the production of polyvinylchloride (PVC);	
<u>Pesticides/biocides</u>		
Aldrin†, Dieldrin†, Endrin† (Aldrin rapidly converts to Dieldrin)	Insecticides*. Endrin also used in rodent control*.	Production and use to be eliminated under the Stockholm Convention, subject to some transitional exemptions.
Atrazine and Simazine	Herbicide (used extensively in maize and sugarcane agriculture to control weeds)*	Production and use have been phased out in some countries (where it has largely been replaced by less persistent herbicides. Still produced and used in some other countries, where controls on use are seen as sufficient to keep it out of the water environment.

Substances	Sources and Main Uses[1]	Production and Related Developments
Chlordane†	Insecticide, particularly for termites	Production and use to be eliminated under the Stockholm Convention. The Global Environment Facility in 2006 provided USD 14 million for a programme to enable China to achieve this.
Chlordecone†	Insecticide, particularly used in banana culture	No current production or use is known.
Dichlorodiphenyltrichloroethane (DDT)†	Originally use widely as a broad-spectrum insecticide, now almost exclusively for controlling insect disease-vectors*	Production and use controlled under the Stockholm Convention. 18 Convention Parties have registered to continue to use DDT for disease-vector control, of which 5 reported no use in their last report. One Party (the Gambia) reported use, but had not registered.
Dicofol	Pesticide, especially for mites on tomatoes and melons*	Some countries have phased out the use of dicofol. It is still used in Brazil, China, India and Israel. Produced by chemically modifying DDT.
Endosulfan†	Pesticide*	Production and use to be eliminated under the Stockholm Convention, subject to specific exemptions.
Heptachlor	Insecticide, especially for soil insects and termites*	Production and use to be eliminated under the Stockholm Convention.
Hexachlorobenzene	Fungicide*	Production and use to be eliminated under the Stockholm Convention.
Lindane (γ-hexachlorocyclohexane (HCH)†, including α-HCH† and β-HCH† isomers (produced in large quantities as by-products to γ-HCH)	Insecticide*	Production and use to be eliminated under the Stockholm Convention, subject to exception for use against head-lice and scabies. Production and use have largely already ceased, but stockpiles of α- and β-HCH exist.
Methoxychlor	Insecticide for use on both animals and plants*	Phased out in the European Union and the United States. Information is lacking on production and use elsewhere.
Mirex†	Insecticide, particularly for termites*; fire retardant*	Production and use to be eliminated under the Stockholm Convention. The Global Environment Facility in 2006 provided US$14 million for a programme to enable China to achieve this.
Pentachlorophenol (PCP) and its salts and esters†?	General pesticide, now widely restricted to use as a fungicide and wood preservative*	PCP is being considered under the Stockholm Convention because it transforms into pentachloroanisole (PCA) which is seen as a problem. PCP has been phased out in the European Union.
Pentachlorobenzene†	Used to make PCBs less viscous*; in dyestuff carriers*; as a fungicide*; as a flame retardant*	No current intentional production or use is known; probably still produced as a by-product in imperfect incineration.
Toxaphene†	Insecticide, particularly used for cotton and soya-bean culture*	Production and use is to be eliminated under the Stockholm Convention.
Aromatics		
Polycyclic aromatic hydrocarbons (PAHs)	Incinerators; large combustion plants; Söderberg-process aluminium-smelting plants; coke plants; imperfect combustion of wood and fossil fuels	Reductions in PAH emissions are being achieved by tighter regulation of vehicles, combustion plants and incinerators, technology changes in aluminium-smelting plants and (in some areas)

SUBSTANCES	SOURCES AND MAIN USES[1]	PRODUCTION AND RELATED DEVELOPMENTS
	(including vehicles)*; coal-tar surface treatments (including creosote)*	elimination of the use of some surface-treatment processes.

Particularly important are:

(a) ***Heavy metals:*** All heavy metals occur naturally and, because of natural weathering processes and the immunity of natural elements to destruction, are found at measurable levels even in waters generally regarded generally as pristine. Some heavy metals (such as cadmium, mercury and lead) are always highly toxic. Others (especially copper and zinc) are essential trace elements in diet or intake for many biota. Some heavy metals, especially copper and arsenic, have been used extensively in the past for plant protection purposes, resulting in widespread additional dispersal and higher concentrations in some areas. In excessive amounts, however, even these can interfere with the absorption of other essential trace elements and, at high levels, become toxic. At lower levels, they also appear capable of affecting the immune systems of biota (Coles et al., 1995; Kakuschka et al., 2007) or their reproductive success (Leland et al., 1978);

(b) ***Persistent organic pollutants (POPs):*** In contrast, POPs are man-made. They are organic compounds (that is, compounds involving carbon, most often combined with hydrogen and/or with chlorine, bromine or other halogens) that resist degradation in the environment through chemical, biological or other processes. Many were developed as biocides (insecticides, herbicides, etc.) since about 1910-1930. Others are used in manufacturing processes or in electrical appliances. From the 1960s, concerns developed about their effects on immune systems and reproductive success, and about their carcinogenic effects. As a consequence of the call in the GPA in 1995, subsequently endorsed by the UNEP Governing Council, the Stockholm Convention on Persistent Organic Pollutants was adopted on 22 May 2001[5] and now provides a global mechanism for controlling the production and use of POPs. Initially, agreement was reached in 2004 that production and use of 12 POPs should be banned or strictly controlled. Since then a further 10 POPs have been brought under the Convention's controls;

(c) ***Polycyclic aromatic hydrocarbons (PAHs):*** PAHs are complex compounds of hydrogen and carbon (and, in some cases, other elements such as nitrogen, oxygen or sulphur). They occur naturally, and are also typically created by imperfect combustion processes. Many, but not all, are carcinogenic and/or affect reproductive success;

It is important to note that the category of hazardous substances is not closed. New substances are constantly being developed, and new uses are constantly being found for a wide range of elements and compounds. The questions whether these substances and elements are toxic, persistent and bioaccumulative and whether

[5] 2256 United Nations *Treaty Series* 119.

their uses present risks to the marine environment need to be kept under continual review. Substances where such questions arise are sometimes referred to as "contaminants of emerging concern" (see, for example, Yuan et al., 2013).

Knowledge of the extent of the presence of hazardous substances in the marine environment is patchy. Some issues, such as the presence in the marine environment of contamination from heavy metals and lindane, have been studied for over 30 years in some areas and, to a lesser extent, have also been studied quite widely around the world. Other issues have only been looked at more recently, and a number have only been examined from the point of view of laboratory tests of substances on marine biota, without monitoring for the presence of the substances in the sea itself or its biota and sediments.

Some hazardous substances reach the marine environment in inflows of water, others are airborne. Waterborne contaminants tend to be found mainly near the inflows, and thus concentrated in estuarial and coastal waters, particularly where they are adsorbed onto particles in the water and settle as sediments. Airborne contaminants are carried much further out to sea, and therefore are found more generally. For some hazardous substances, sampling around the world's continents has shown that they are present in all continents (for example, dioxins and furans (which are most often airborne) have been found in butter samples from all continents, though to a lesser extent in the southern hemisphere (Weiss et al., 2005). Where hazardous substances have been spread worldwide largely by air transport, it can be assumed that they have also reached the ocean. It is known that some POPs have been concentrated on the higher latitudes of northern hemisphere land-masses by a process of volatilization from land and redeposition – sometimes described a "multi-hop" process, as compared with "one-hop" contaminants that are carried in one step to their final destination.

3. Point Sources

The most obvious threats to the marine environment from hazardous substances come from point sources. Such point sources can be either discharges into rivers which ultimately reach the sea, or direct discharges through pipelines into the sea. There can be cases (usually volcanic eruptions) in which natural processes result in the introduction of naturally occurring hazardous substances into the ocean. However, many point sources are large industrial plants which provide a concentrated source from which the hazardous substances pass into the marine environment. Waste-water treatment plants can also be regarded as point sources, since they can concentrate hazardous substances from a substantial area and funnel them to a single discharge point. Historically, it was the impact of such point sources on inland waters that first gave rise to concern. In England, effective legislation was introduced as early as 1875 (Rivers (Prevention of Pollution) Act 1875). Similar legislation followed in other industrialized countries. Because of the then current belief in the almost infinite absorptive capacity of the sea, general measures on discharges and emissions reaching and affecting the sea were not adopted until the 1970s. Initially the measures were “end of the pipe” methods of removing contaminants from discharges and emissions. Gradually, the emphasis has moved more to “clean technology”, where the contaminants are not used in, or not generated by, the process. Among the most significant point sources in respect of hazardous substances are the following:

(a) ***Large combustion plants:*** Since fossil fuels naturally contain other minerals, such as heavy metals, their combustion releases those elements. Since the gases from combustion are released to the air, large combustion plants are a significant source for airborne transport of contaminants to the ocean. Many large combustion plants do not have sufficient scrubbers to clean the flue gases. Such plants are particularly significant for emissions of mercury: all forms of coal-burning account for 24 per cent of the total global estimated annual anthropogenic releases of 1,960 tons (estimate range: 304 to 678 tons) (UNEP, 2013a based on a 2010 inventory). This estimate differs in absolute amount and relative proportion of the total emissions from an earlier one in 2008 based on a 2005 inventory: in 2008 all forms of coal-burning were estimated to be in the range of 1,230 to 2,890 tons, and to constitute the largest sector emitting mercury; the change is due to revised estimates of emissions from domestic heating (revised downwards from 2008 to 2013), and emissions from artisanal gold refining (revised upwards from 2008 to 2013, and thus estimated in 2013 to be the largest mercury-emitting sector). If the 2005 inventory figures are compared with the 2010 inventory figures and the same methodology used is considered, and the estimates employ the same 2010 methodology, the emissions in 2010 from coal combustion in power generation and industrial uses combined are the same as, or perhaps slightly higher than, in 2005. The fact that emissions from this sector are not higher, even though new coal-fired power plants are being built, rests on the improving combustion efficiency and emissions controls in most parts of the world (UNEP, 2008; UNEP, 2013a). Emissions of mercury from large combustion plants should eventually be controlled by the actions required under the Minamata Convention on Mercury of 10 October 2013 (Minamata Convention). Coal-fired power stations are also significant sources of cadmium, zinc and PAHs. Cement production is another form of large combustion plant which can emit heavy metals both from the fuel and from the raw materials: in 2013, mercury emissions from this sector were estimated on the basis of the 2010 inventory at 173 tons (estimate range 65.5 – 646 tons) (EU BREF, 2013; UNEP, 2013a).

Between 2001 and 2012, the proportion of the total amount of electricity generated by coal-fired power stations declined or remained stable in much of the world (Africa, Europe and Central Asia, North and South America, South Asia). It can therefore be expected that emissions of mercury from such power stations reaching the ocean will stabilise or decline. The proportion, however, grew steadily in East Asia – from 51 per cent to 63 per cent (although China’s proportion of coal-derived electricity remained stable at around 80 per cent). Unless even greater efforts are made to control emissions of hazardous substances from coal-fired power stations, the levels of contaminants reaching the ocean from this source in that part of the world are likely to increase (World Bank, 2014).

The pattern of development in cement production is different from that of coal-fired power generation: except in Europe, there has been significant growth over the past decade: 33 per cent in the Americas, 66 per cent in Oceania, over 200 per cent in Africa and over 250 per cent in Asia. This increase in production appears to have been accompanied by marked improvements in the quality of control of emissions: for one of the most significant, mercury, the UNEP 2013 estimate of mercury emissions from this sector was lower than the 2008 estimate (173 tons as against 189 tons) (UNEP, 2008; UNEP, 2013a).

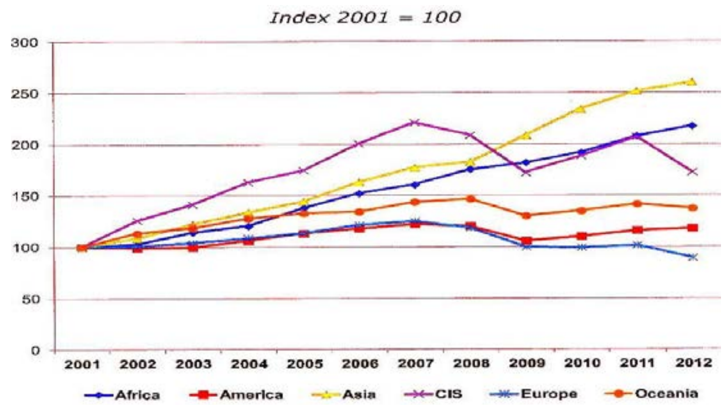

Figure 1 World Cement Production 2001-12. Source: European Cement Association, 2014.

(b) ***Chemical industries:*** Chemical industries can give rise to a wide range of contaminant emissions and discharges: the products themselves may present problems – as can be seen from the list of substances in Table 1 – and other hazardous substances can be released either in the production process or as part of the waste stream. Where efforts have been focused on combating pollutant discharges and emissions, chemical plants have usually been high on the list of targets. For traditional technologies, the focus has to be on removing pollutants from the waste streams and preventing leaks during the process. Increasingly, however, the focus is on new technologies which do not present the same pollution problems as the traditional technologies (for example, the membrane process in chlor-alkali production and the "no-chlorine" processes in paper and pulp production).

The world of chemical production is, moreover, changing fast. Measuring the overall situation is not easy, because of the wide range of products that come under the umbrella of the chemical industries. One measure that can be used to indicate the scale of change in the chemical industries, however, is the value of the goods produced. In real terms, the statistics of such product values will show changes in the level of activity of the chemical industries in different countries. Such statistics will, of course, hide changes in chemical industries where bulk production of basic chemicals is replaced by production of specialist chemicals of higher intrinsic value. Nevertheless, they can give an overall view of the way in which the world's chemical industries are changing (see Appendix to this chapter):

(i) Between 2003 and 2012, the value of the total world output of chemicals rose by 12 per cent in real terms;

(ii) In 2003, 60 per cent by value of the world output of chemicals was in North America and Europe. By 2012, this had dropped to 40 per cent;

(iii) In contrast, the proportion by value of world chemical production in Asia and the Pacific rose from 29 per cent to 49 per cent, in spite of a reduction of 24 per cent in the value of Japanese chemical products. The value of Chinese chemical products in real terms rose by 293 per cent between 2003 and 2012 (to 29 per cent of total world production), that of Singapore by 74 per cent, that of India by 56 per cent, and that of the Republic of Korea by 32 per cent.

Figure 2 World Chemical Production by value in 2003 and 2012. Source: Appendix to this chapter.

There has therefore been a significant change in the potential for the impact of chemical industries on the marine environment, with a change of focus from the Atlantic Ocean basin to the Pacific Ocean basin.

Certain types of chemical plants merit specific mention: chlor-alkali plants, polyvinyl chloride (PVC) plants and titanium-dioxide plants.

(c) ***Chlor-alkali plants:*** Chlorine and caustic soda are basic requirements for many chemical industries. Since 1892, they have been produced by electrolysis of brine. The (original) mercury-cell process uses a layer of mercury as the cathode, which is constantly withdrawn and reacted with water. The resulting water discharges, unless purified, have a high mercury content. This original process is increasingly being replaced, initially by the diaphragm process (which used an asbestos diaphragm) and now by the membrane process, neither of which use mercury. One hundred mercury-cell process plants still exist in 44 countries. Existing plans will result in this number diminishing to 55 plants in 25 countries by 2020 (UNEP, 2013b).

(d) ***Polyvinyl chloride plants:*** PVC plants use various processes to convert vinyl chloride monomer into the plastic PVC which has manifold uses throughout the world. Global production in 2009 was around 30 million tons, representing a growth of 50 per cent since 1995. The world's production capacity is significantly higher (around 48 million tons/year), but the economic recession reduced use of this capacity (Deloitte, 2011). Production levels are expected to recover quickly and to continue to grow. Capacity in China has grown particularly rapidly, from about 375,000 tons in 2001 to nearly 16,000,000 tons in 2008.

The adverse environmental impact from PVC plants consists mainly of the emission of dioxins and furans and the risks from the emission of vinyl chloride monomer (VCM), a known carcinogen. Although the immediate threats are to the vicinity of the plants, there is evidence that all these emissions can reach the marine environment (OSPAR, 2000).

In China, there is an additional problem in that the large majority of PVC plants in that country develop the PVC by an acetylene-based process starting from coal, in contrast to plants in the rest of the world which mainly use an ethylene-based process starting from oil. The production of the acetylene from coal requires a catalyst, which is currently mercury chloride (although research is in hand to develop a mercury-free alternative). About 574-803 tons/year of mercury are used (2009 figures), of which about 368-514 tons are lost in waste (China, 2010). It is not clear how much of this reaches the sea.

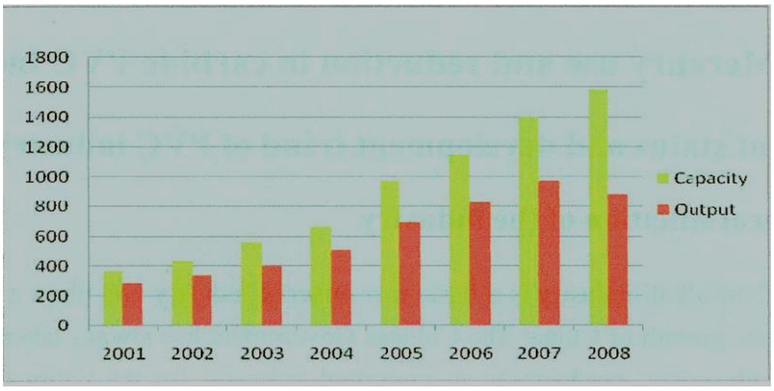

Figure 3. China: PVC production capacity and output (in 10,000 tons). Source: Chlor-Alkali Industry Association in China, 2010.

(e) ***Titanium dioxide (TiO_2) plants:*** TiO_2 is used as a very white pigment, mainly in paint, plastics and paper. Different production processes are used for the two main mineral sources (ilmenite and rutile), but both produce large amounts of acid waste. In Europe in the 1970s, much of this was disposed of into the sea, either by pipeline or dumping. This gave rise to concern about effects on fish (Vethaak et al., 1991). Improved waste management methods, mainly through recycling the acid or its use in other products, have now largely removed these problems in Europe. Estimated production of TiO_2 is about 1.4 million tons/year each in Europe and the United States, and about 2.3 million tons/year in China, where production is growing rapidly (USGS, 2013).

(f) ***Mining:*** Mining is a significant part of the economy in a number of States, and everywhere is a basic source of supply to manufacturing industry. In 2010, eight States were responsible for over 70 per cent by value of global production from mining: Australia (15.6 per cent), China (15.0 per cent), Brazil (10.2 per cent), Chile (6.8 per cent), the Russian Federation (6.2 per cent), South Africa (5.9 per cent), India (5.6 per cent) and the United States (5.0 per cent). Mining formed over a tenth of Gross Domestic Product (GDP) in Papua New Guinea (33.4 per cent), Zambia (23.8 per cent), Chile (14.7 per cent), Ghana (12.7 per cent) and Peru (12.0 per cent) (ICMM, 2012).

From the point of view of the aquatic environment, the main concern about mining is the disposal of waste. Large amounts of pulverized rock mixed with water ("tailings") are produced, which have to be stored or disposed of. Except that some mines remove cyanide (used in extracting metals), tailings are not treated before disposal. They therefore contain a large range of potentially hazardous substances. They can also cause problems through siltation and smothering of biota, particularly in the sea. Concerns about the consequent problems for the sea go back 600 years in south-west England (Worth, 1953). Tailings are most often stored on land behind dams. Catastrophic collapses of tailings dams can release toxic materials into watercourses and thence to the sea. Twenty-six tailing-dam failures in 15 countries have been noted between 2000 and 2014 (WISE, 2014). Not all of these will have affected the sea, but the 1996 event at Marinduque, in the Philippines, clearly had effects on the marine environment, making the sea much more acid, with elevated heavy-metal levels, as well as smothering a substantial area of the seabed (USGS, 2000). In some cases, tailings are also disposed of directly into rivers and into the sea. In 2012, there were 12 mines (1 in Indonesia, 5 in Norway, 4 in Papua-New Guinea, 1 in Turkey and 1 in the United Kingdom) practising disposal direct into the sea (IMO, 2012). In all cases the aim was to have a pipeline taking the waste well below the bulk of marine life in the water column. However, the tailings smother a large area of seabed, and are capable (depending on the local geology) of introducing substantial amounts of heavy metals into the marine environment.

(e) ***Smelting:*** The smelting of metals, both ferrous and non-ferrous, can result in the emission of heavy metals to the atmosphere, which may then be deposited in coastal catchments and transported to the sea by watercourses, or deposited direct onto the sea by wet or dry deposition. For example, around 70 per cent of the emissions of lead to the atmosphere in Australia in 2003/04 were from non-ferrous metal processing (though not generally adversely affecting the marine environment). Ferrous-metal production also leads to emissions of lead to air: in Europe in 2000, it was estimated that lead emissions from iron and steel production was about half as much again as that from non-ferrous metal production. There is no recent estimate of the amount of global emissions of lead to air, but in 1983 it was estimated at 87,000-113,000 tons (this will have reduced substantially since with the reduction in use of leaded petrol/gasoline) (UNEP, 2010). When properly managed, metal smelting can have very limited adverse effects on the marine environment. However, production of many metals is increasing rapidly (see, for example, the figures in Table 1 for heavy metals). Likewise, the production of iron and steel is also increasing rapidly: pig-iron production increased by 85 per cent between 2001 and 2011 to 1,158 million tons/year (BGS, 2012). In particular, pig-iron production in China over the same period rose by over 300 per cent, so that it is now over half the annual world production. Even if the levels of emissions per ton of production are kept steady at the present level, the total load will increase in proportion.

Aluminium presents a special case. The primary form of production is by electrolysis. The Söderberg process became the predominant method. The carbon anode used in this process is consumed at a rate of about 0.5 ton for every ton of aluminium produced (ALCOA, 2014). Much of this carbon used to be emitted as polycyclic aromatic hydrocarbons (PAHs). Over time, better controls on PAH emission have been introduced, and more importantly, the Söderberg-process aluminium-smelting plants are being phased out – only about 7 per cent of global aluminium production is now by that process. From 2005 to 2010, world primary aluminium production increased by almost 30 per cent to 41.6 million tons (over one-third of which is in China, which has no Söderberg plants), but PAH emissions to air were reduced by 50 per cent per ton of aluminium produced (IAI, 2013);

(f) ***Paper industry:*** Paper mills can give rise to a variety of environmental concerns. In relation to hazardous substances, the problems arise mainly from bleaching the pulp, a process needed for the production of most paper. During the period before the 1970s-1980s, the pulp and paper industry was the source of inputs giving rise to concern: polychlorinated dioxins and furans (PCDDs and PCDFs) were detected in effluents of pulp mills, resulting from the long-established use of chlorine in bleaching. It has proved possible to reduce this problem substantially by a mix of measures: principally by replacing elemental chlorine with chlorine dioxide and other oxygen-containing substances and by introducing closed systems and recycling the bleach-plant effluent. New processes have also been introduced: the Elemental-Chlorine-Free (ECF) and the Totally-Chlorine-Free (TCF) processes, which avoid the by-products of the chlorine bleaching process (EU BREF, 2001).

The paper industry has seen substantial growth in the period 2001-2012: worldwide production has increased by 23 per cent to just over 400 million tons. This growth has not been uniform: production in Canada and the United States has declined, while production levels in Africa, Europe, Oceania and the Russian Federation have remained more or less stable. The growth has been in Asia and Latin America, where production has increased over this period by 76 per cent and 34 per cent, respectively; production in China alone has grown by nearly 220 per cent to 103 million tons in 2012 (see Table 1 in Appendix to this chapter). Even if levels of contaminants per ton of production are kept at previous levels, growth on this scale will substantially increase the total load of contaminants finding its way to the sea. There is evidence (Zhuang, 2005) that the expansion of Chinese paper-making capacity has been accompanied by improved environmental management, but data to show the total effect do not seem to have been collated.

(g) ***Incinerators:*** Increasingly, significant amounts of domestic and municipal waste consist of plastics containing chlorine. Much of this waste is disposed of through incineration. Where this happens in uncontrolled open-air burning, there is a substantial risk of the formation of dioxins and furans: almost any combination of carbon, hydrogen, oxygen and chlorine can yield some polychlorinated dioxins/furans under the wrong conditions (Altwicker et al., 1990). Even where the incineration takes place in purpose-built incinerators, a risk of such formation remains, especially where controls do not ensure that appropriate temperatures are reached during combustion or where devices to scrub or filter the flue gases are not installed or not properly maintained and operated. The same problem arises where incineration is used to dispose of wastes from industries that produce waste containing hazardous substances: if incineration is not properly done, both the hazardous substances in the waste and other newly created hazardous substances may be emitted.

(h) ***Fertilizer production:*** The production of phosphate fertilizer produces substantial amounts of waste from the rock that has to be processed. Heavy metals, especially cadmium, are found in this waste, and reach the sea either from direct discharges or, in some cases, by leaching from land-based waste storage. Total world fertilizer production has risen by 23 per cent between 2002 and 2011, rising even more in South America (89 per cent) and East Asia (78 per cent). Production in Africa represents a fifth of the total world production, and concern has been raised about the impacts of some of the discharges (Gnandi et al., 2006).

(i) ***Desalination:*** Desalination is very important in some parts of the world where fresh water is in short supply (see chapter 28). Desalination plants require massive intakes from the sea (capacity in the north and central Red Sea, for example, is over 1,750 megalitres[6] a day (PERSGA, 2006), and in the Persian Gulf, it is over 10,900 megalitres a day (Sale et al., 2011)) and produce substantial discharges. The potential contaminants are found in discharges of heated, concentrated brine and of chemicals added to improve performance and to prevent corrosion (chlorine, copper and antiscalants). The effects of the brine discharge are mostly local (within tens of metres of the discharge), and are quickly diluted and dispersed, but in extreme cases they can be traced for several kilometres (Roberts et al., 2010). They are particularly significant in areas with high tidal ranges where the discharge is above the high-tide mark, where they can affect biota in the inter-tidal zone. Chlorine concentrations in discharges in the Red Sea average 0.25 ppm (standard swimming-pool chlorination is 1.0-3.0 ppm), and so local biocidal effects are possible. Copper concentrations in the discharges of a typical desalination plant are around 15 ppb, significantly above generally accepted criteria for satisfactory water-quality. In Red Sea desalination plants, about 9 tons of antiscalants a day are used and discharged. They have a relatively low toxicity and are diluted rapidly, and are therefore judged unlikely to pose a significant threat, but there

[6] A megalitre is equivalent to one million litres or one thousand cubic metres.

is limited information on them. In general, the conclusion of a review of articles studying these problems was that discharge site selection is the primary factor that determines the extent of ecological impacts of desalination plants (Roberts et al., 2010). Overall, the Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden (PERSGA) determined in 2006 that desalination was not a threat to the Red Sea (PERSGA, 2006). No overall assessment of effects in the Persian Gulf appears to have been made (Sale et al., 2011).

4. Diffuse Sources

There are manifold diffuse sources of hazardous substances that can reach and affect the ocean. The main pathways are through surface water runoff in watercourses (both from liquid discharges and from leaching), groundwater discharges, and wet and dry deposition of emissions to the atmosphere. The most significant processes are waste disposal, routine combustion processes, abrasion, use of biocides and accidents. All of these affect both land and sea, and there is nothing special about the methods to control these processes for the purpose of protecting the marine environment. It is, however, necessary to ensure that marine aspects of the impact of all hazardous substances are specifically considered in decision-making on control measures, because the effects of some hazardous substances are significantly greater (or different) than in freshwater or land environments. Other compounds released from diffuse sources that have been suggested for consideration include pharmaceuticals (both human and veterinary) and cosmetic ingredients (such as musk xylene). Evaluation of such substances has not yet shown general agreement that there are significant problems which need action, although some regulatory bodies are keeping some of these substances under observation.

4.1 Waste disposal

Adverse effects on the marine environment from waste disposal can arise from a wide range of processes. Leaching from land-fills into which waste has been deposited is probably the major source. This can be significant for brominated flame retardants (PBDEs and related substances (see entry in Table 1)). Industrial liquid waste will often enter into municipal waste water treatment systems – these can be regarded as point sources, but at the same time they usually collect waste water from a large area. The waste entering municipal waste water treatment systems also includes runoff from accidents involving the spilling of hazardous substances. A large number of hazardous substances will form part of materials in waste streams. Among the heavy metals, lead and cadmium are particularly significant given their widespread use in batteries: 80 per cent of all lead used in OECD countries is used in batteries (ILZG, 2014). Although there is a strong economic interest in recycling such lead (and lead is the most recycled non-ferrous metal), there is a substantial risk that it will eventually leach to the ocean from badly managed waste streams. The same applies to other heavy metals (such as cadmium) which are also used in batteries and electronic equipment.

Plastics containing chlorine compounds (such as PVC) form a significant part of waste streams in most countries. These therefore also present problems for the marine environment if disposal is not properly managed, because inadequately controlled combustion can result in the release of hazardous substances to the marine environment.

The Global Alliance on Health and Pollution (which includes, among others, UNEP, UNDP, UNIDO and the World Bank) has developed an international register of over 2,000 sites in middle- and low-income countries (as defined by the World Bank) where pollution problems are occurring (http://www.pollutionproject.org/about-tsip/). A large number of these sites are in the immediate coastal zone. Although this exercise has been focused on implications for human health, the extent to which the problems at these sites consist of uncontrolled releases of hazardous substances gives an indication of the extent to which badly managed waste-disposal sites and other sites with toxic deposits can present a problem for the ocean. In more developed countries, there are also problems from sites with toxic deposits, but remediation efforts appear to have been implemented in many of these cases (Ericson et al., 2013).

4.2 Use of Pesticides

The purpose of pesticides is that they are spread into the environment in order to control the pest against which they are aimed. If the pesticides are applied improperly, if surplus pesticides are not adequately disposed of, or if the chemicals involved have a sufficiently high degree of persistence before they degrade, they will eventually reach the marine environment. As shown above, action has been taken to remove from use many of the pesticides that give rise to most concern about their impact on the marine environment because of their toxicity, persistence and bioaccumulativity. However, even where such pesticides have been removed from the market, stocks often remain, and residues from past use persist in the soil and watercourse sediments that can make their way to the sea. In some cases, the judgement has been made that controls on the use of the pesticide will be sufficient to guard against harm to the oceans (see above on atrazine). In all these cases, therefore, there is a strong case for continued monitoring to check that bans are working and that usage conditions are being observed.

4.3 Routine combustion processes

Some hazardous substances, especially polycyclic aromatic hydrocarbons (PAHs), can be created by relatively common combustion processes, such as wood-burning stoves (Oanh et al., 1999). Uncontrolled burning of waste, such as rubber tyres, is another such source. Such emissions can be limited by better design of stoves and by better management of waste disposal. However, effective control of all such sources is unlikely to be practicable.

4.4 *Abrasion*

Some hazardous substances are used in products such as vehicle tyres and paint, where eventual abrasion is likely to free them into the environment, as the tyres are worn down or the paint peels off. Significant progress was made in reducing this kind of contaminant with the replacement of white lead paint by paint based on titanium dioxide (Waters, 2011). Substitution of this kind is the most effective way of resolving this kind of problem.

4.5 *Small-scale gold-mining*

A traditional, but crude, refining process for recovering gold from ore uses mercury to create an amalgam with the gold and subsequently vaporizes the mercury to leave high-quality gold. The vaporized mercury becomes an airborne contaminant, and can reach and affect the ocean. Artisanal gold-mining has been estimated to account for about 25 per cent of global gold production (Donkor et al., 2006). The predominant refining process in artisanal gold-mining is the mercury-amalgam process. It is judged to be the sector with the largest source of mercury emissions to the air (UNEP, 2008). The Minamata Convention on Mercury (2013) requires States bound by the Convention which have artisanal and small-scale gold mining to reduce and, where possible eliminate the use and environmental releases of mercury from such mining and processing.

4.6 *Accidents*

Wherever hazardous substances are produced, stored or transported, there is scope for accidental releases. There is no effective global source for statistics of accidents involving hazardous substances (ILO, 2007). In several countries, systems have been established to provide for the location, design and inspection of premises where hazardous substances are produced or stored and of vehicles carrying them, and for response to, and investigation of, significant accidents that do occur (for example, the European Union Seveso Directive (EU, 1996)).

5. Regional View of the Impact of Hazardous Substances on the Ocean

The lack of data makes it impossible to develop a general assessment of the relative impacts of hazardous substances on the ocean in the different parts of the world. In some areas, regional or national efforts have produced time-series of observations that enable trends to be established. But even here, the need to work through a number of institutions often means that clear comparisons between the absolute situation in different areas is not possible: different measuring techniques may be used; significantly different ranges of varieties of chemicals may be observed; and there is often an absence of any ring-testing to validate the accuracy of different institutions.

5.1 Open ocean generally

Observations of the presence of heavy metals and other hazardous substances in the open ocean[7] are very limited, including areas around islands and archipelagos in the open ocean. Few specific studies of pollution in the open ocean have been conducted. What information is available is concentrated on the north Atlantic. The Indian Ocean and the southern parts of the Atlantic and Pacific Oceans have hardly been assessed.

For hazardous substances, the most significant route for impacts on the open ocean is transport through the atmosphere: hazardous substances can be carried either as aerosols (that is, microscopically fine particles of solids or liquids suspended in the air) or as gases (particularly in the case of mercury). The substances can remain suspended for long periods, and thus travel long distances. However, available evidence does not show that heavy metals in the open ocean are at levels causing adverse effects on humans or biota – with the exception of mercury. The load of mercury in the atmosphere has approximately tripled in the last two centuries. This has led to a probable doubling of inputs to the ocean. However, evidence also exists that, in some open-ocean areas such as near Bermuda, levels of mercury in the sea have decreased from the early 1970s to 2000. Nevertheless, there is good evidence that some fish concentrate mercury in their flesh to levels which give rise to risks for humans who eat a lot of such fish. Mercury concentrations in midwater fishes are several-fold higher than in epipelagic fishes at the same trophic level. Mercury levels in deep-sea fishes, such as morids and grenadiers, are substantially higher than in shelf-dwelling fishes, such as cod; notably long-lived fishes on seamounts, such as orange roughy and black cardinalfish, have mercury levels near or at the levels normally regarded as permissible for human consumption (0.5 ppm). Human activities have also led to higher levels of airborne inputs of lead and cadmium, but in these cases there is no evidence yet of toxic effects ((Monteiro et al., 1996; Koslow, 2007; GESAMP, 2009).

For persistent organic pollutants (POPs), there is no doubt about their ability to be carried long distances through the atmosphere – this was one of the major reasons for the concerns that led to the Stockholm Convention. Although the effects of deposition of POPs on land have been extensively studied, information specifically on the levels of deposition of these substances in the open ocean and their possible effects is very limited (GESAMP, 2009). Estimates suggest that concentration of POPs may be an order of magnitude higher in deep-sea than in near-surface-dwelling fishes, and the deep sea has been referred to as their ultimate global sink (Froescheis et al., 2000; Mormede and Davies, 2003).

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[7] As explained in Chapter 1, "open ocean" in this Assessment refers to the water column of deep-water areas that are beyond (that is, seawards of) the geomorphic continental shelf. It is the pelagic zone that lies in deep water (generally >200 m water depth).

5.2 Arctic Ocean

In the Arctic, downward trends are reported in concentrations of the POPs controlled by the Stockholm Convention. Levels in marine mammals, some seabirds and polar bears are still high enough to cause adverse effects on their immune systems and reproductive success, but this is not the case for fish. Of the heavy metals, lead concentrations in biota were assessed as low in 1997 and since then they have been found to be decreasing. Mercury has been found at relatively high levels in whales, but the presence of selenium is also high enough to neutralize any detrimental effects. Parts of northern Canada have substantial natural levels of cadmium. The runoff from these deposits is reflected in the marine biota. Local pollution from heavy metals and some POPs is found around some mines, especially on the Kola Peninsula (Russian Federation) and some military installations, such as the Distant Early Warning System stations in northern Canada. In addition, one report suggests that 12 million drums of unknown, but potentially polluting, contents have been left in the Russian Federation: remediation is under way (AMAP, 1997; AMAP, 2009). Nevertheless, atmospheric transport and transport by ocean currents of pollutants are still significant issues for the Arctic (Stemmler et al., 2010; Ma et al., 2015).

5.3 Atlantic Ocean and Adjoining Seas

5.3.1 North-East Atlantic Ocean, North Sea, Celtic Seas

The North-East Atlantic is one of the most thoroughly assessed areas of the ocean: two comprehensive assessments were carried out in 2000 and 2010 (OSPAR, 2010). It is also an area where major efforts have been made since 1975 to reduce inputs of hazardous substances. Assessments are made of each of the contaminants studied, rather than attempting to combine them in a single indicator.

Statistically robust results show major reductions in the amounts of heavy metals being introduced into the marine environment in this area (Green et al., 2003). This is also demonstrated from monitoring by the OSPAR Commission (see Table 2).

Table 2 Percentage change in inputs of some heavy metals into North Sea and Celtic Seas 1990-2006.

Area	Cadmium - riverine input	Cadmium - direct discharges	Lead - riverine inputs	Lead – direct discharges	Mercury – riverine inputs	Mercury - direct discharges
North Sea	-20%	-75%	-50%	-80%	-75%	-70%
Celtic Seas	-60%	-95%	No trend	-90%	-85%	-95%

Source: OSPAR, 2010

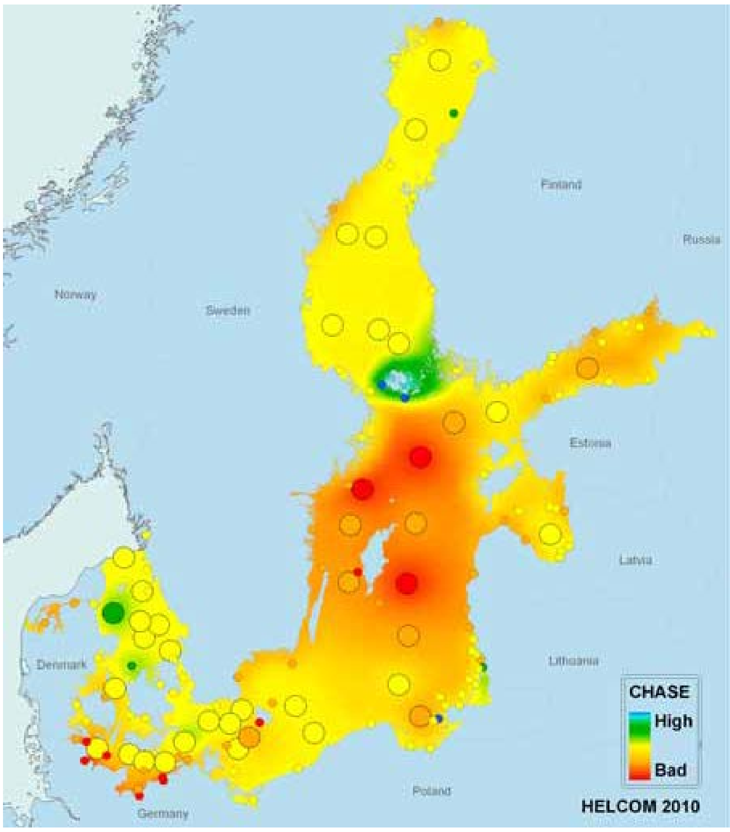
A large part of these reductions was achieved in the 1990s: progress since 1998 has been slower. Concentrations in some areas, such as around the industrial estuaries of the Rhine (the Netherlands), the Seine (France) and the Tyne, Tees and Thames (United Kingdom), as well as in certain industrialized estuaries in Norway (Inner Sørfjord) and Spain (Ría de Pontevedra) and the inner German Bight, are still at levels giving rise to risk of pollution effects. High concentrations of cadmium found in fish and shellfish around Iceland seem to be linked to volcanic activity, such as the eruption of the Eyjafjellajökull volcano in Iceland in 2010 (OSPAR, 2010).

Trends in concentrations of PAHs in fish and shellfish are predominantly downward, especially in the Celtic Sea but, in many estuaries and urbanized and industrialized locations, they are still at levels which pose pollution risks. In many locations in coastal waters, concentrations of at least one polychlorinated biphenyl (PCB) congener pose a risk of causing pollution effects. Similar concern has arisen over the exposure to perfluorinated compounds, particularly perfluorinated octanoic sulfonate (PFOS). Over 25 years after being banned, PCBs are thought to be possibly causing adverse biological impacts in some areas: the Faroese authorities (Denmark) have initiated a risk management process for the human consumption of pilot-whale meat (a traditional food source in the Faroe Islands) because of the presence of POPs.

Observations show that concentrations in fish and shellfish of the pesticide lindane (which has been banned since the early 1980s) are decreasing generally. However, concentrations in some localities are still of concern. These probably represent past use on nearby land. The more recent cessation of the use of other pesticides classed as hazardous substances is seen as likely to achieve similar results.

5.3.2 Baltic Sea

The Baltic Sea is an enclosed water-body with very limited water exchange with the North Sea and the North-East Atlantic. Periodically major inflows occur, bringing in substantial amounts of new water with high salinity from the North Sea. These inflows were fairly frequent until about 1980, but thereafter became infrequent, occurring in 1993, 1997, 2003, 2011 and 2014. The large quantity of freshwater from the Baltic catchments, together with the limited exchange with the North Sea, allows the build-up of hazardous substances in the basins of the Baltic Sea. Like the North-East Atlantic, the Baltic has a long-standing practice of assessment of the state of the marine environment. The Helsinki Commission has developed a multimetric indicator-based assessment tool. This has been used to integrate the status of contamination by individual chemicals and biological effects at specific sites or areas into a single status value termed the "Contamination Ratio" (CR). This CR is the ratio of the current status (the measurement of the concentration of a substance or biological effect) and a threshold level or quality criterion for that particular substance or biological effect. The CRs of all substances or indicators are grouped under four different ecological objectives (contaminant concentrations in the environment generally, contaminant concentrations in fish, biological effects on wildlife and levels of radioactivity) and integrated to yield a status classification ("high", "good", "moderate", "poor" or "bad") for each ecological objective. The ecological objective receiving the lowest status classification serves as the overall classification of the assessed site or area, giving the classification of the "hazardous substances status" of that site or area. The criteria used are not all uniform, but may include nationally set criteria. Therefore the results are not strictly comparable between assessment units. The overall picture is shown in the adjacent map, based on assessments at 144 sites, where "high" indicates good conditions and "bad" bad conditions of the marine environment with respect to hazardous substances (HELCOM, 2010a; HELCOM, 2010b).



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 4. Baltic Sea: Combined Hazardous Substances Contamination Index. Source: HELCOM, 2010a.

Overall, there has been a steady and substantial improvement in the quality of the Baltic in respect of hazardous substances over the past two decades. This is due partly to the focus of the Baltic States in tackling the hotspots of pollution that were identified, and partly to the closure during this period of a number of the more polluting plants in countries in economic transition, as a result of economic circumstances. In the countries in economic transition, the former large installations have been superseded by a larger number of small and medium-sized enterprises, which makes the task of adequate regulation more difficult. There is, nevertheless, much further progress to be made before the goals set by the Helsinki Commission are reached.

5.3.3 Mediterranean Sea

The Barcelona Commission has carried out assessments of many aspects of the state of the Mediterranean over the last four decades. Nevertheless, there are major gaps in the data available for assessment: much more is known about contaminants in the sea off the northern coasts of the Mediterranean than about those off the southern and eastern coasts. Major sources of discharges and emissions of heavy metals are seen as the cement industry, electricity generation, metal mining and smelting, and fertilizer production. Many waste-water treatment plants are also seen as a problem. Based upon the available information, high concentrations of heavy metals (especially lead and/or mercury) in sediments and shellfish (blue mussel (*Mytilus galloprovincialis*)) are found around Barcelona, Cartagena and Malaga (Spain), Marseilles/Fos and Toulon (France), the Gulf of Genoa, the Po delta, the Gulf of Trieste and around Naples (Italy), the coast of Croatia, Vlora Bay (Albania), around Athens, Thessaloniki and Kavala (Greece), around Izmir (Turkey) (though subsequent Turkish Government tests have found nothing that would require action to be taken), Haifa Bay (Israel), the Nile delta (Egypt) and the coastal lagoons of Bizerta and Tunis (Tunisia). Insufficient data were available for robust trend analysis, but the limited analysis possible showed a general pattern of stable to declining trends, although in some places there were slightly increasing trends (UNEP, 2012).

In the past, high levels of POPs have been measured in top predators in the Mediterranean. More recently, a study of data from 1971-2005 has concluded that the contamination of sediments by POPs is mainly associated with major urban areas, the mouths of major rivers, major ports and coastal lagoons, and that there has been a general decline in such concentrations. A 2011 study identified the areas of the mouth of the River Ebro and Barcelona (Spain), the mouth of the Rhône and Marseilles (France), the coast from Nice (France) to Livorno (Italy), the area around Genoa (Italy), the coast of Croatia and the port of Piraeus (Greece) as showing elevated levels of PCBs. Most of these locations, together with the Bay of Naples, the coast of the Marche and the Gulf of Trieste (Italy), the area around Dürres and Vloa Bay (Albania), the Ambracian, Saronic and Thermaic Gulfs (Greece), the area around Izmir (Turkey), the Bay of Tunis (Tunisia) and the Bay of Algiers (Algeria) also showed moderate to high levels of chlorinated pesticides. Again, data were insufficient for trend analysis (UNEP, 2012). Turkish authorities have subsequently indicated that there have been no findings which would have required measures to be taken.

5.3.4 Black Sea

Contamination by pesticides and heavy metals has not been judged to be a basin-wide problem by the Black Sea Commission. Elevated concentrations of heavy metals in bottom sediments and biota near river mouths, hot-spots and ports are decreasing. Pesticides are mostly introduced through rivers and streams discharging from agricultural areas. However, as a result of economic change, the use of these substances has decreased considerably and no longer presents a major hazard, except where their use was very intensive in the past. Elevated concentrations of HCH (mainly lindane) have been found along the coastal areas influenced by the Danube River: some sites near the Danube Delta were found to be among the highest levels of HCH recorded globally. In 2002, evidence was found of DDT and its breakdown products, probably from inappropriate storage of expired pesticides (Black Sea Commission, 2008; Heileman et al., 2008c).

5.3.5 North-West Atlantic

As in the Arctic, the problems of airborne transport of POPs found in the Arctic are also of concern in Labrador and Newfoundland. The main influence further south in Canada is the outflow of the St Lawrence River, which drains a large part of the heavily populated interior of Canada and the United States. The work derived from the efforts of the Canada/United States International Joint Commission (on shared water bodies) has done much to reduce the hazardous-substance content of this outflow. Similarly much has been done in Canada to address the problems posed by coastal industries, especially paper and pulp mills. As a result, hazardous substances are not seen as a priority for the Canadian Atlantic (Janowicz et al., 2006). Nevertheless, some problems remain, particularly in the Saguenay Fjord, where mercury and other metals were found in beluga whales at levels sufficient to cause concern. Cultured and wild scallops have been found to contain cadmium above the levels acceptable for human consumption, although its main source seems to be of natural origin (Dufour et al., 2007).

In the United States, the National Coastal Condition Reports (NCCR) (of which the latest NCCR IV was completed at the end of 2012, though based on data from 2003-2006 (EPA, 2012)) have been prepared regularly since 2000. They consider indices of water quality, sediment quality, benthic quality, coastal habitats and fish-tissue contaminants. They examine the coastal waters (estuaries and embayments) and also look at some of the waters further offshore. The sediment-quality index and the fish-tissue contaminants are the most relevant to the question of contamination by hazardous substances, although the benthic index (which looks at the structure of the benthos and the extent to which it is affected by pollution) can also be illuminating. The sediment-quality index is based on measurements of toxicity, amounts of contaminants (heavy metals, PAHs and PCBs) and total organic carbon content in samples taken from a range of stations, which number thousands across the country. The fish-tissue contaminants index is based on samples of fish for human consumption of species appropriate to the region. The indices for the sampling stations within a region are used to classify the region as “good”, “fair” or “poor”, according to the proportions of sampling stations within different bands of the indices.

The United States divides its Atlantic coast into two regions: the North-East region (Maine to Virginia, including Chesapeake Bay), and the South-East region (North Carolina to Florida). The North-East region is the most heavily populated part of the United States, and the overall condition of its coastal waters is judged to be “fair”. The positions on the sediment-quality index (overall “fair”) and the fish-tissue contaminant index (overall “fair to poor”) are shown in the pie charts below. The problem zones for both sediments and fish-tissue contaminants are principally in Great Bay (New Hampshire)[DDT, Hg], Narragansett Bay (Rhode Island), Long Island Sound, the New York/New Jersey harbour area [DDT, Hg], the Upper Delaware Estuary and the western tributaries of Chesapeake Bay. The impaired ratings for the large majority of these sites were due to the presence of PCBs. Advice was also issued at various dates during 2006 against eating fish caught along about 84 per cent of the length of the coast of the North-East region – mainly because of the presence of

PCBs. Those marked [DDT] also showed, above the thresholds, moderate to high levels of DDT and those marked [Hg] showed moderate levels of mercury. The NCCR also considered whether trends could be detected over the period from 2001 to 2006. No overall statistically valid trends were noted, but a significant reduction was observed in the areas judged as "poor" on the element of the presence of contaminants from Narrangassett Bay to the Delaware River.

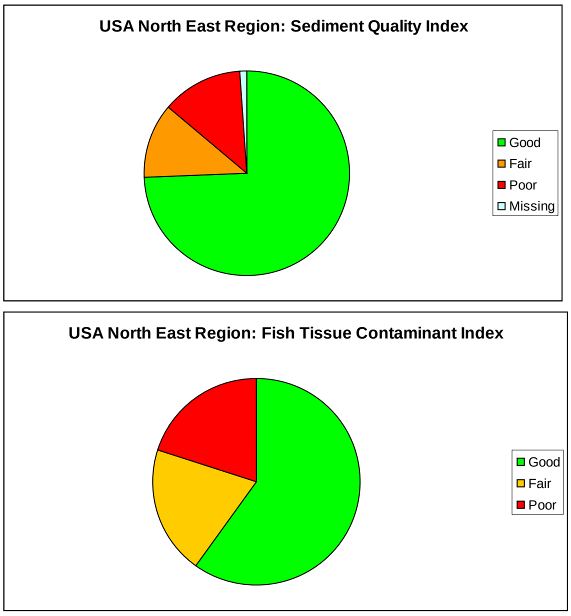


Figure 5. United States North-East Region Sediment and Fish-Tissue Contaminants Indices. Source: EPA, 2012.

In Chesapeake Bay, where a combination of problems of toxic contaminants and eutrophication resulted in 2009 in a special programme involving the Federal Government and the five States, the most recent report shows that for PCBs and mercury, many locations in the catchment have an impaired ecological status, largely stemming from concentrations in sediments and in fish tissue (where human consumption often has to be discouraged). A limited number of locations have severe problems from dioxins/furans, PAHs, some chlorinated pesticides (aldrin, chlordane, dieldrin, DDT/DDE, heptachlor epoxide, mirex), and some metals (aluminium, chromium, iron, lead, manganese, zinc). For other products (atrazine, some pharmaceuticals, some household and cosmetic products, some brominated flame retardants and biogenic hormones), it was not possible to assess where severe impacts were occurring, but it is known that that the substances have potential for adverse, sub-lethal ecological effects (EPA et al., 2012).

The NCCR also looked at the condition of the Mid-Atlantic Bight: that is, the seas between Cape Cod and Cape Hatteras out to the edge of the continental shelf. None of the contaminants for which tests are made for the sediment-quality index or the fish-tissue contaminants index was found in excess of their corresponding Effects Range Medium (ERM) values (values probably causing harmful effects). Only three chemicals (arsenic, nickel, and total DDT) exceeded their corresponding Effects

Range Low (ERL) values (values possibly causing harmful effects), and these lower-threshold exceedances occurred at only a few sites. This implies that, on the same basis as for waters closer to the shore, this sea area should be regarded as in a "good" condition.

The overall condition of the South-East region (North Carolina to Florida) was judged to be fair. The sediment-quality index was judged to be "fair to poor" and the fish-tissue contaminants index was rated "good". No statistically significant trends were observed for the period 2001-2006. Conditions in the bight between Cape Hatteras and the south of Florida were also examined. Three metals (arsenic, cadmium, and silver) were found at concentrations between ERL and ERM values at 9 of the 50 offshore sampling sites, but no sites had more than one ERM value exceeded. Nevertheless, advice was in force in the whole area against eating king mackerel (*Scomberomorus cavalla*), because of mercury contamination.

A separate study – the National Mussel Watch – looked over a 20-year period (1986 – 2005) at levels of contamination by hazardous substances in mussels and oysters along the coast. For the Atlantic coast, this has shown in general no significant trends in contamination by heavy metals, but some locations show a decreasing trend. It has shown no significant trend in cadmium contamination in Chesapeake Bay, in spite of major efforts at reduction, and has shown significant increasing trends in mercury and lead at a few locations in the zones where problems were identified by the NCCR. Nevertheless, it has shown significant decreasing trends in contamination by POPs all along the Atlantic coast of the United States (Kimbrough et al., 2009; Mussel Watch, 2011).

5.3.6 Wider Caribbean

Information on hazardous substances in the Wider Caribbean (that is, the Gulf of Mexico, the Caribbean Sea and the Atlantic immediately east of the Leeward and Windward Islands) is mixed: for the United States and its dependencies, the same type of information is available as for the Atlantic coast; elsewhere, there is no systematic record.

The overall condition of the United States Gulf coast is judged to be "fair". The sediment-quality index was judged to be "fair to poor" and the fish-tissue contaminants index was rated "good". The areas rated "poor" on the sediment-quality index lay mainly around the Florida Keys, the coasts of Alabama and Mississippi, Galveston (Texas) and the Texas coast south of Corpus Christi. No statistically significant trends were observed for the period 2001-2006, but a substantial reduction in areas failing the test for the presence of contaminants was found. Nevertheless, in 2006 advice was in force along the whole of the United States Gulf Coast against the eating of king mackerel (*Scomberomorus cavalla*), because of mercury contamination (EPA, 2012). The Mussel Watch has likewise shown some locations with decreasing trends in heavy-metal contamination and a general decreasing trend in contamination by POPs (Mussel Watch, 2011).

There is no recent, comprehensive compilation and analysis of inputs of hazardous substances to the remainder of the Wider Caribbean (Fernandez et al., 2007), although specific areas are known where problems of this kind are found (Cartagena

Bay, Colombia; Puerto Limon, Costa Rica; Havana Bay, Cuba; Kingston Harbour, Jamaica; and some locations in Puerto Rico). These largely result from the discharge of untreated waste-water from local industries. Mining also presents significant problems, particularly mining of bauxite in Guyana, Jamaica and Suriname and (to a lesser extent) in the Dominican Republic and Haiti (GEF, 1998; EPA, 2012). Heavy and increasing usage of agricultural pesticides is reported from the mainland countries of Central America, and from Jamaica and Cuba (UNEP-UCR/CEP, 2010). In addition, chlordecone (an agricultural pesticide, the use of which was prohibited from 1993) gave rise to concern in fish and seafood from Martinique in 2003 (Bocquenéa and Franco, 2005). The presence of the same chemical in seafood was still preventing it being marketed in 2013 (*Le Monde*, 2013).

5.3.7 North Atlantic open ocean

The OSPAR Quality Status Report 2000 (OSPAR, 2000) examined the situation in the open ocean of the Atlantic (beyond the 200-m isobath) east of 42ºW longitude. This showed limited information about the state of the marine environment in this area. No later comprehensive survey has been made. The conclusions on contamination by hazardous substances were that:

(a) Airborne inputs of hazardous substances from land were very significant: probably equal to the effects of waterborne inputs reaching the deep Atlantic;

(b) Anthropogenic inputs to the North Atlantic were higher than those to other deep ocean areas, representing up to 25 per cent of the total estimated global deposition rates for a range of substances;

(c) Nevertheless, the level of concern for the area about contamination by hazardous substances was rated as low.

5.3.8 South-East Atlantic

The coastal waters of the South-East Atlantic are dominated by three currents: from north to south, the Canaries Current, the Guinea Current and the Benguela Current. These three areas have been adopted for the tasks of addressing the problems of the marine environment. Little detailed information is available about land-based sources of pollution in these areas. What is clear is that the main problems are “hot spots” in the proximity of the principal coastal cities: Abidjan (Côte d’Ivoire), Accra (Ghana), Cape Town (South Africa), Casablanca and Rabat (Morocco), Dakar (Senegal), Douala (Cameroon), Lagos and Port Harcourt (Nigeria), Luanda (Angola) and Walvis Bay (Namibia). Most of the industries operating in the region are located in or around these coastal areas and discharge untreated effluents directly into sewers, canals, streams and rivers that end up in the ocean. Outside the immediate areas of discharge, however, the effects are limited by the strong marine current (Heileman, 2008b).

Nevertheless, some specific problems are more than local. Mercury emissions from artisanal gold-mining in West Africa are a general problem. This gold production is an important part of the national economies of several States in the area, but significant levels of mercury have been found in many West African rivers, and therefore present risks to the marine environment (Donkor et al., 2006). Other mining activities also present significant threats. For example, phosphate mining at Hahatoé-Kpogamé in Togo results in discharges of tailings and other waste with high levels of cadmium and lead being found in fish and crustaceans (Gnandi et al., 2006).

Samples from the Korle (Accra, Ghana), Ebrié (Abidjan, Côte d'Ivoire) and Lagos (Nigeria) lagoons, show heavy metals in the sediments up to three (Cd), six (Hg) and eight (Pb) times more than those from uncontaminated areas, and in shellfish at or above WHO standards for Cu, Pb and Zn (GCLMEP, 2003).

5.3.9 South-West Atlantic

Although there are studies of several locations along the coast of Brazil, there does not appear to be a comprehensive study of the levels of heavy metals or POPs for the coastal sea of Brazil as a whole. It is clear that there are many untreated direct and riverine discharges from coastal cities which produce significant local effects: São Paulo, with a population of over 11 million and a concentration of petrochemical and fertilizer industries, and Rio de Janeiro, with over 6 million inhabitants, are the most significant, but there are other examples, such as Rio Grande. The River Amazon also has a major effect on the northern part of the area. The diffuse sources contributing to this effect include agricultural pesticides and mercury from small-scale gold mining (Heileman, 2008a, Heileman, 2008c; Heileman and Gasalla, 2008; Niencheski et al., 2006).

The situation is much the same further south: there are hot-spots associated with major coastal cities, but no overall survey. The River Plate is a major influence, since it drains areas with a high concentration of potentially polluting industries, and is assessed as highly polluted. Apart from that, the most serious area is around Bahia Blanca, where the general level of contamination has been assessed as moderate (Marchovecchio, 2009). However, the San Matias Gulf has also been identified as having relatively high levels of cadmium and lead (Heileman, 2008e).

5.3.10 South Atlantic open ocean

Very limited information is available on levels of contaminants in the central South Atlantic. Nevertheless, samples of skipjack tuna, tested for brominated flame retardants as a marker for widely dispersed POPs, show levels that are lower than in the open ocean of the Pacific (Ueno et al., 2004).

5.4 Indian Ocean

No comprehensive studies or time series of the incidence of hazardous substances in the Indian Ocean exist, although there are a number of local, one-off studies.

5.4.1 Western Indian Ocean

In general, the areas of both the Agulhas Current (the waters off the coasts of eastern South Africa and Mozambique and around the Comoros, Madagascar, Mauritius, Réunion (France) and the Seychelles) and the Somali Current (the waters off the coasts of the Federal Republic of Somalia, Kenya and the United Republic of Tanzania) are not heavily polluted with heavy metals or POPs (Heileman et al., 2008b). Nevertheless, some top predators (yellowfin tuna) are reported to show high concentrations of HCB and lindane by comparison with the same species elsewhere, although levels of PCBs and DDTs are not so high. The residues of PCBs, DDTs, lindane and HCB were higher than those measured in 1999 (Machado Torres et al., 2009).

However, relatively severe localized problems are found near major cities and industrialized areas in all the countries. The main industries that contribute towards chemical contamination in this region include: manufacturing, textiles, tanneries, paper and pulp mills, breweries, chemical, cement, and sugar and fertilizer factories. Coastal solid-waste dumps add to the problems. The intensive use of agro-chemicals, such as DDT, aldrin and toxaphene, has been common throughout the region. Inappropriate utilization, storage and dumping of agrochemicals are a growing concern. Direct discharge of wastes from fertilizer factories is a severe problem in the region (Heileman et al., 2008a). Mozambique has instituted a legal and institutional framework for the management and treatment of municipal and industrial waste, including the development of sanitation infrastructure (landfills, industrial and wastewater treatment plants.

5.4.2 Red Sea, including the Gulf of Suez and the Gulf of Aqaba, and the Gulf of Aden

Slow water turnover makes the Red Sea particularly vulnerable to pollution build-up. Pollution is severe in localized areas around industrial zones and facilities, including especially the Gulfs of Suez and Aqaba and near the port of Aden. The installations include phosphate mines, desalination plants, chemical industrial installations and oil production and transportation facilities. In 2003, elevated levels of some heavy metals were found near Suez, in the Sharm al Maya Bay in Egypt (PERSGA, 2006; EEAA, 2003).

5.4.3 Persian Gulf

Major manufacturing industries operate in the coastal States of the Persian Gulf, based largely on the raw materials from oil and gas extraction, producing fertilizers, chemicals, petrochemicals, minerals and plastics. The demand for fresh food has also led to intensive agriculture and the use of pesticides. All these activities have resulted in waste-water and runoff taking heavy metals and other hazardous substances into the semi-enclosed sea of this area (Sale et al., 2011).

5.4.4 Arabian Sea and waters west of India, the Maldives and Sri Lanka

Overall, pollution from hazardous substances in the northern Arabian Sea has been assessed as severe in several coastal hotspots, but in general it has been evaluated as moderate. The major issues in these hotspots are heavy metals from industrial installations. Other hotspots are found at the mouths of some major rivers (for example, the Tigris, Euphrates, Karun, Hileh and Mand rivers). Other hotspots involving PAHs have been recorded in coastal areas receiving effluents from highly industrialized zones. In waters off Pakistan, chlorinated pesticides are more prominent. Since persistent organic pesticides are not to be marketed in the States bordering the Arabian Sea, these findings likely result from the remains of historic use (Heileman et al., 2008a).

Along the coasts of India the picture is mixed. High concentrations have been noted, for example, off the Maharashtra coast. Near Mumbai, sample fish have also been shown to have concentrations of lead, cadmium and mercury above levels that are generally regarded as fit for human consumption (Heileman et al., 2008a; Deshpande et al., 2009). Around the Alang-Sosiya ship-breaking yards in Gujarat, India (which employ 40,000 people), on the basis of samples taken in 2001, particularly high levels, above approved limits of heavy metals in sediments, have been reported (Janil et al., 2011). On the other hand, along the Gujarat coast, the concentrations of mercury in sediments have decreased to below the limits of detection, reflecting the decrease in its concentrations in land-based effluents. Along the Maharashtra coast, mercury levels in sediments have declined and are currently about 0.1µg/g. Along the Karnataka coast, observations have been made off Mangalore and Karwar. At both locations, concentrations of mercury in sediments have shown decreasing trends. Along the Kerala coast, concentrations of mercury were low at all sampling locations, and exhibited declining trends (NIOT, 2014).

In Sri Lanka, most industrial plants are concentrated near Colombo. They lack waste-water treatment capacity, and textile and metal-finishing plants are discharging significant quantities of some heavy metals. The Lunawa coastal lagoon has been ruined by such discharges (BOBLME, Sri Lanka, 2011).

5.4.5 Waters east of India, the Maldives and Sri Lanka (Bay of Bengal, Andaman Sea, Malacca Strait)

The dominant influence in the north of this area is the River Ganges, the second-largest hydrological system on the planet. The Bay of Bengal Large Marine Ecosystem Project (BOBLME) has organized recent surveys of marine pollution in all the coastal States. These show that much information is available, but there are no time series or sufficient metadata for comparisons.

In the waters off India, along most of the coast, concentrations of mercury in sediments have declined: off Tamil Nadu, concentrations were observed at <0.1 µg/g; off Andhra Pradesh, there has been a substantial decline to a similar level; and the coast off Orissa exhibited a decline to concentrations of 0.1-0.2 µg/g. In contrast, off West Bengal mercury content of sediments showed a marginally increasing trend both in-shore and near-shore: recent values of up to 0.3 µg/g suggest continued release of industrial waste containing mercury (NIOT, 2014). Hot-spots for heavy-metal pollution are found in the Ganges estuary (the Hooghly River, Diamond Harbour, Sagar Island and Haldia). Further south, hot-spots have been reported at Bhitarkarnik, Visakhapatnam, Ennore, Cuddalore, and Tuticorin. At all these places, pollution from heavy metals results from direct industrial discharges and the inputs of rivers carrying industrial discharges. Pollution from POPs stems mainly from pesticide-manufacturing plants and ineffective storage of withdrawn pesticides, as well as the leaching of pesticides and past uses of PCBs. Recent surveys indicate significant levels of DDT, PCBs and dieldrin in both near-shore and off-shore fish in the Bay of Bengal (BOBLME, India, 2011).

For Bangladesh, the picture is very similar. In addition, heavy metal pollution is particularly noticeable near the Sitakunado ship-breaking area of Chittagong. Reports from 2004 suggest that banned organo-chlorine pesticides are being sold on the black market and that some are being used in fish-processing plants (BOBLME, Bangladesh, 2011).

In the waters off Myanmar, significant levels of heavy metals have been reported in fish samples, but at levels below those at which human consumption is not advised. Organochlorine pesticides are not regarded as a problem because of lack of availability for use (BOBLME Myanmar, 2011).

In the Andaman Sea off Thailand, levels in sediments of lead and cadmium were reported in 2009 that were well above levels regarded elsewhere as likely to cause harm, and in 2007 levels of mercury in sample fish were reported that were above Thai and many other national standards for human consumption (BOBLME, Thailand, 2011).

On the western coast of peninsular Malaysia, levels of contamination of hazardous substances observed in 2009 and 2010 were in general within national standards, which are consistent with generally recognized standards. Exceptions were off the coast of Perak, where significant numbers of samples showed lead and cadmium levels in excess of these standards. This is attributed to major historic mining activities in that State (BOBLME, Malaysia, 2011).

5.4.6 Waters north and west of Australia

In general, the waters north and west of Australia are in very good condition. The large-scale mining in the catchments has not generally caused problems with hazardous substances because of the low rainfall and consequent absence of major watercourses. There are some localized problems around the Gulf of Carpentaria, such as Darwin Harbour and Melville Bay (Nhulunbuy, Northern Territory), where a localized, biologically dead area has been created by mining wastes (SE2011 Committee, 2011).

5.4.7 Indian Ocean open ocean

As with other open-ocean areas, information on levels of contamination from hazardous substances is limited. Studies in 1996 around the Chagos Archipelago (over 500 km from the nearest continental land) showed that only some PCBs and lindane were above the limits of detection, and then only just. The conclusions therefore were that atmospheric transport was the main source, and that the area was amongst the least affected coastal areas (Everaarts et al., 1999). Air sampling around the Chagos Archipelago has also concluded that the atmosphere over the Indian Ocean in 2006 was substantially less contaminated from atmospheric POPs than it was according to the available data from the 1970s and 1990s (Wurl et al., 2006). Samples of skipjack tuna from the mid-Indian Ocean were studied as a way of examining the distribution of airborne contaminants. They showed (like all tuna studied from around the world) detectable levels of brominated diphenyl ethers, but at lower levels than in the north Pacific (Ueno et al., 2004; Tanabe et al., 2008).

5.5 Pacific Ocean

5.5.1 North-East Pacific

- *Waters west of Canada and the mainland of the United States*

The United States applies the general principles of the National Coastal Condition Report to its Pacific coasts, although the sheer scale of the Alaskan coast makes some aspects inappropriate. For Alaska, the results show an overwhelmingly good condition: as with the Alaskan Arctic coast, there are some local natural sources of heavy metals, but the presence of other hazardous substances is mainly from long-range transport through the seas or the atmosphere (EPA, 2012).

In Canada, the situation is much the same for the northern and central coast of British Columbia, where population density and levels of industrial development are low. Further south, however, some hot-spots with severe adverse effects from high concentrations of chlorinated hydrocarbons and heavy metals have been found, for example, in the Port Moody arm of the strait separating Vancouver Island from the mainland (Belan, 2004).

For the area of the Alaska current as a whole, samples of biota obtained during 2003-08 have generally not detected concentrations of PCBs, pesticides or mercury at levels of concern (PICES, 2009).

The waters off the western coasts of the contiguous United States are also assessed as being "good", with 86-89 per cent of the sampling stations being put in this class on the individual indices. The areas where the sampling stations fail to achieve "good" status are mainly around San Francisco, Los Angeles and San Diego in California (EPA, 2012). Nonetheless, the Mussel Watch shows significant decreasing trends of levels of heavy metals and other hazardous substances at sampling stations all along the Pacific coast of the contiguous United States, except for Puget Sound, where increases in the levels of lead contamination have been found (Mussel Watch, 2011).

- *Waters west of Mexico, Guatemala, El Salvador, Honduras, Nicaragua and Costa Rica*

From the point of view of contamination by hazardous substances, the waters west of the countries of Central America are affected mainly by the discharges from local, relatively small-scale industries and agricultural runoff. The overwhelming majority of industrial effluent is discharged to the sea without treatment, and usage of pesticides is one of the highest in Latin America (Heileman, 2008e).

5.5.2. East Asian Coastal Seas - General

At the regional level, no information is regularly collected on inputs of hazardous substances and their effects. Levels of heavy metal contamination in the East Asian coastal seas are, however, known to have been rising over the last two decades, largely due to untreated municipal waste-water and industrial effluents. The rise was rapid in some areas, particularly in coastal waters of China, over the twenty years to 2000. For most of the area, there is no general evidence that this has ceased. In the Gulf of Thailand, lead and cadmium have been found at high levels near the mouths of all major rivers. In some areas, the levels of heavy metals in fish and shellfish have made them unsuitable for human consumption. Depth profiles of sediment samples suggest in many cases that these inputs of heavy metals are linked to recent rapid growth of electronics, ship-painting and chemical industries.

Persistent organic pollutants are measurably present in most coastal areas of the East Asian Seas at levels higher than many other parts of the world, but studies have shown decreasing levels of those which had previously been banned. Endosulfan has been found in most coastal sediments, especially off Malaysia, suggesting recent use. Both DDT and PCBs are found at levels above limits generally recognised as tolerable, but in some areas (for example, the Macau estuary in China), studies have shown that such levels peaked as much as twenty years ago (UNEP/COBSEA, 2010).

5.5.3 Coastal waters of China

At the national level, the Chinese authorities have been carrying out systematic monitoring of the coastal waters and coastal sediments as part of their national environmental monitoring programme. For water quality, their system uses an assessment classification based on a range of parameters covering not only hazardous substances but also problems caused by non-hazardous waste elements. As far as hazardous substances are concerned, levels are reported as satisfying national standards. The combined assessment is shown below in the section on nutrients. In addition, the Chinese authorities study sediment quality in relation to hazardous substances. Decreases in concentrations have been observed generally since 1997. However, in 2010 areas around 36 coastal pollutant discharge outfalls did not meet the sediment quality requirements, mainly because of the levels of copper and cadmium, and some of the area showed a worsening (China, 2012). In Hong Kong, China, waters, monitoring focused specifically on hazardous substances has been undertaken to evaluate the effects of the stringent measures to combat pollution from these substances. These monitoring programmes have demonstrated a steady decline between 1991 and 2012 of, in total, about 30 per cent in the levels of heavy metals in sediments at the west end of Hong Kong Island. Even there, however, levels in enclosed bays used as typhoon shelters can be much higher. Sediments around Hong Kong, China, show a slight decline in levels of PCBs (Hong Kong, China, 2013). Other evidence (from sea-bird feathers) shows that there are high levels of mercury in the South China Sea (Watanuki et al., 2013).

5.5.4 Yellow Sea and waters between Japan and the Korean Peninsula

The absence of data, and (even where they are available) their incompleteness and lack of consistency, make any assessment of the impact of hazardous substances on the Yellow Sea as a whole very difficult. There seems to be little doubt, however, that inputs of hazardous substances are at levels which give rise to concern, largely because of the discharges of untreated industrial waste-water (NOWPAP, 2007). Where detailed information is available about specific areas, however, there is good evidence of improvement: in the waters around Japan, for example, levels of PCB concentrations in both fish and shellfish have decreased by over 75 per cent between 1979 and 2005. Nevertheless, concentrations in both fish and sediments remain at levels sufficient to cause concern, particularly in enclosed sea areas surrounded by big cities (Japan MOE, 2009). Local sources of pollution, mainly from mining, are also significant along the northern coast of the Russian Asia-Pacific Region (Kachur et al., 2000).

5.5.5 North-West Pacific (Kuroshio and Oyashio Currents)

The areas east of the Japanese main island and the islands north and south of it are significantly less affected by industrial, mining and agricultural activities than the seas along the coast of the Asian mainland, except close to the Japanese main islands. In enclosed sea areas surrounded by big cities on the Japanese main island, there are levels of contamination from POPs much (up to five times) higher than on the western coast. This is particularly the case in Ise Bay and Tokyo Bay (I. Belkin et al., 2008; Heileman and Belkin, 2008; Japan MOE, 2009).

5.5.6 North Pacific open ocean

Apart from some major island ports, such as Pearl Harbor, Hawaii (which shows evidence of PCB contamination (EPA, 2012)), contamination from heavy metals and other hazardous substances is not a major concern in the central north Pacific. However, mercury concentrations in the North-East Pacific increased between 2002 and 2006 and modelling suggests an average increase of 3 per cent per year between 1995 and 2006 (Sunderland et al., 2009). Samples of skipjack tuna from the western part of the central north Pacific, studied to assess airborne transport of contaminants, showed higher levels of brominated diphenyl ethers than samples from the central Indian Ocean and off Brazil. The suggestion is made that this might be the result of atmospheric transport from locations in south-east Asia where waste goods containing these fire retardants were being dismantled (Ueno et al., 2004).

5.5.7 South-East Pacific (Waters west of Panama, Colombia, Ecuador, Peru and Chile)

Little new information on the situation in this area as a whole is available since the survey conducted in 2000 by the Permanent Commission of the South Pacific (CPPS, 2000). In respect of discharges of hazardous substances, this survey showed a major problem with mining waste, particularly in the south of Peru and the north of Chile. The mining industry in these countries is mainly in the coastal areas. A substantial number of mines disposed of their waste directly into the sea, and others indirectly through rivers: none of these wastes were treated. The areas said to be highly polluted were at the mouth of the River Rímac (into which a number of mines discharged) and between Pisco and Ite in Peru, and around Chañaral in Chile. In the north of Chile, as well, there were beaches which had been used in the past for the disposal of mine waste, and from which heavy metals (especially copper) were leaching into the sea. In addition, a heavy load of agricultural pesticides was thought to be present: nearly 5,000 tons of active ingredient were thought to be used annually in the 1990s, resulting in what was judged to be serious pollution in the coastal areas of the province of Chiriqui in Panama, in the extreme south of Colombia, around Guayaquil in Ecuador, around Pisco in Peru, and in regions VI (Rancagua), VII (Talca), VIII Concepción), X (Puerto Montt) and XI (Cohaique) in Chile.

5.5.8 South Pacific open ocean

Even less is known about the contamination of the open ocean by hazardous substances in the South Pacific than in the other open-ocean areas. The island States of the area have neither major industrial sites, nor major mines. A wide range of pesticides has been used for local agriculture, although the most hazardous are no longer used. A result of this use, however, is that residues have been found in the soil, as well as stocks of persistent organo-chlorine pesticides and contaminated sites where the pesticides were stored (Samoa, for example, has three such sites). There were also a number of electrical devices containing PCBs (the Federated States of Micronesia had 13.5 tons). With Australian and GEF assistance, programmes are in place to dispose of stocks and remediate contaminated sites. The States have, however, recorded their concern about lack of capacity to prevent the accidental creation of dioxins and furans from imperfect incineration (Samoa, 2004; FSM, 2004).

5.5.9 Waters east of Australia and around New Zealand

The waters to the east of Australia are renowned for the Great Barrier Reef – the world's largest coral reef system. Although the catchments draining into this part of the sea are not heavily industrialized, they contain intensive agriculture, especially for sugar cane. The pesticides (and other runoff) from these catchments are judged likely to cause environmental harm, particularly to the central and southern parts of the Great Barrier Reef. Models of the mean annual loads of a range of common pesticides (ametryn, atrazine, diuron, hexazinone, tebuthiuron and simazine) show that inputs are in the range of 16-17 tons of active ingredient. The total pesticide load to the Great Barrier Reef lagoon is likely to be considerably larger, given that another 28 pesticides have been detected in the rivers (Lewis et al., 2009; RWQPP, 2013).

Further south, the coast of the south-eastern part of Australia is the most heavily populated area in the country: nearly one-third of the total population is in central New South Wales. Port Jackson (Sydney Harbour) is locally contaminated with heavy metals, especially lead and zinc, and a large proportion of the estuary has sedimentary metals at concentrations where some adverse biological effects can be expected. Most of the contamination is a legacy of past poor industrial practice, but some evidence exists for continuing entry of contaminants, probably from leaching (Birch, 2000). Further south, in the State of Victoria, the Government acknowledges that data on the condition of marine and coastal ecosystems are not gathered in a comprehensive manner, making assessment of the condition of coastal and marine systems difficult. Estuarine and bay systems, such as Port Phillip Bay (Melbourne), Western Port and the Gippsland Lakes, have impaired water quality, partly from industrial and agricultural sources (Victoria, 2013).

In New Zealand, a study was made of dioxins, furans, PCBs, organochlorine pesticides, estuarine sediments and shellfish. The catchments covered ranged from highly urbanized to areas relatively remote from anthropogenic influences. The results showed that concentrations of these substances in New Zealand estuaries are low, and in most cases markedly lower than concentrations reported for estuaries in other countries, although concentrations in some estuaries are approaching those reported elsewhere for urbanized estuaries (NZMOE, 1999). Examination of sediment cores from Tamaki Creek, near Auckland (New Zealand's largest city) has shown a four-fold increase in levels of heavy metals since the European settlement of the area, with most of the increase in the last 50 years. Tamaki Estuary is classified as a polluted area (Abrahim et al., 2008). The estuaries around Auckland and near other large urban areas seem likely to be subject to the same pressures.

5.6 Southern Ocean

Levels of contamination by heavy metals and other hazardous substances are low. Long-distance transport through marine currents and the atmosphere means that measurable levels of contamination are found, but not at levels that give rise to concern. Some of the research stations have accumulated waste contaminated with heavy metals and other hazardous substances. Australia has removed a quantity from the Thala Valley base (Australian Government, 2011). Recently, brominated flame retardants are reported to have escaped from McMurdo Sound base (NGN, 2014).

6. Endocrine Disruptors

As discussed above, hazardous substances are usually defined in relation to the qualities of being toxic, persistent and liable to bioaccumulate. Toxicity is usually defined in relation to being fatal when ingested, to causing cancers (carcinogens), to causing birth defects (teratogens) or to causing mutations (mutagens). Many of the substances regarded as hazardous substances within these accepted definitions were also shown to affect endocrine systems and thus to interfere with the reproductive success of individuals and populations, and were therefore described as “endocrine disruptors”.

In the 1990s, a consensus emerged that certain substances outside the accepted definitions of hazardous substances could also disrupt endocrine systems, and thus affect the ability of individuals and populations to reproduce successfully. In the marine context, the issue was highlighted by the discovery that tributyl tin, which had been adopted widely as a component in anti-fouling treatments for ships' hulls, had a severe effect at very low concentrations on molluscs: initially, the effects were observed at concentrations so low that they could not be detected by the then available methods of chemical analysis. The effects were referred to as “imposex”, and took the form of females developing male sexual characteristics and thus becoming infertile. In some harbours, whole populations of molluscs disappeared. Where such substances were not within the accepted definitions of hazardous substances, new initiatives were needed. The question of “endocrine disruptors” for those concerned with the marine environment therefore became more focused on substances which are not within the accepted definitions of hazardous substances, but which may nonetheless have serious effects on the health of the marine environment (OSPAR, 2003).

The case of tributyl tin is discussed further in Chapter 17 (Shipping). Systems have been developed, principally by the Organization for Economic Cooperation and Development (OECD), to test substances to see whether they have the potential to disrupt endocrine systems (OECD, 2012).

In the application of these testing procedures, some substances not otherwise identified as hazardous substances have been identified that are, or may be, of particular concern to the marine environment. These include:

(a) *Nonyl phenyl ethoxylates:* These are used as emulsifiers, dispersive agents, surfactants and/or wetting agents. These degrade quickly to nonyl phenyls and short-chained nonyl phenyl ethoxylates, which are toxic to aquatic organisms and are thought to have endocrine-disrupting properties. The main users are the industrial, institutional and domestic cleaning sectors (30 per cent of use in Europe; other significant sectors in Europe are emulsion polymerisation (12 per cent), textiles (10 per cent), chemical synthesis (9 per cent) and leather (8 per cent)). Estimated use in Western Europe in 1997 was 76,600 tons. Action has been taken within the European Union and is proposed in the United States (OSPAR, 2009; EPA, 2010);

(b) *Estrogenic contaminants*: There is some evidence that human-derived steroids, such as estradiol and ethinyl estradiol (the active ingredient of the contraceptive pill) can affect aquatic biota. In fresh water, intersex conditions induced in male fish (trout) in rivers in England were attributed to ethinyl estradiol from sewage (Desbrow et al., 1998; Routledge et al., 1998; Tyler and Jobling, 2008). In contrast, androgenic effects have been found in female fish in rivers carrying pulp and paper mill effluents (mosquito fish) and feedlot effluent (fathead minnows) (Orlando et al., 2004). Whether such substances persist enough to continue to cause such effects after a lapse of time, and how the substances might operate in more dynamic or more dilute environments (such as the sea) is not clear;

(c) *Phthalates*: Phthalates are a class of chemicals most commonly used to make rigid plastics (especially PVC) soft and pliable. They can leach from PVC products, particularly when they enter waste streams. Phthalates can affect reproduction and development in a wide range of wildlife species. Reproductive and developmental disturbances include changes in the number of offspring and/or reduced hatching success and disruption of larval development. They generally do not persist in the environment over the long term, but there is evidence that environmental concentrations are above levels that give rise to concern in some aquatic environments. (Engler, 2012; Oehlmann et al., 2009).

7. Oil

The United States National Research Council has carried out two major studies, in 1985 and 2003, on the amounts of oil that enter the marine environment, both for

United States waters and for the world as a whole (NRC, 2003). The studies concluded that the global estimates of hydrocarbons from land-based sources were particularly uncertain. The 2003 study placed the best estimate of runoff from land globally at 140,000 tons/year, but recognized that this could be as much as 5 million tons, or as little as 6,800 tons. This compares with its estimate of:

(a) The amounts of oil spilled (on average) in the process of extracting hydrocarbons from the seabed. Here the best estimate was 38,000 tons, within a range of 20,000 tons to 62,000 tons;

(b) The amounts of oil seeping naturally into the sea from submarine seeps, such as those off south California. Here the best estimate was 600,000 tons/year, within a range of 200,000 tons to 2 million tons;

(c) The total amount of hydrocarbons entering the sea from all sources. Here the best estimate was 1.3 million tons/year, within a range of 470,000 tons to 8.3 million tons.

Land runoff is therefore a significant component of the impact of hydrocarbons on the sea. As discussed in chapter 17 (Shipping), however, the significance for the marine environment depends crucially on the location: warm, sunny zones will result in much more rapid breakdown of the hydrocarbons by bacteria into harmless substances. Likewise, in areas with high levels of natural seepage of hydrocarbons, oleophilic bacteria will often be abundant and thus the breakdown of anthropogenic inputs will be quicker than in areas with little or no natural seepage. Moreover, within the land-based sources, much of the runoff is the result of relatively large numbers of relatively small accidents and mishaps, which are difficult to prevent. Mitigation, in the form of well designed drainage systems, accident-response systems and public education, has to be the main response.

Oil refineries, however, can represent significant point-sources of hydrocarbon discharges that can reach and affect the sea. No global information seems to be available on losses and discharges from oil refineries. In some areas the impact on the marine environment is serious. In the Persian Gulf, heavy (>200 µg/g) contamination of sediments in the central offshore basin is reported, and attributed to industrial effluents from onshore industries (Elshorbagy, 2005). Efforts in Europe and North America have shown, however, that it is possible to reduce this impact substantially. In Europe, CONCAWE (the oil companies' environmental organization) reports that, under pressure from regulators, the oil companies have diminished substantially the amounts of oil discharged in process water from refineries in relation to throughput:

Table 3. Levels of oil content of aqueous discharges from European oil refineries.

Year	Throughput (million tons per year)	Oil content of water discharges per ton of throughput (g per ton of throughput)		Year	Throughput (million tons per year)	Oil content of water discharges per ton of throughput (g per ton of throughput)
1981	440	24.0		1997	627	1.86
1984	422	12.1		2000	524	1.42
1987	449	10.3		2005	670	1.57
1990	511	6.54		2008	748	1.33
1993	557	3.62		2010	605	1.30

Source: Baldoni-Andrey et al., 2012.

8. Nutrients and Waterborne Pathogens

8.1 General

The second main aspect of land-based inputs that cause marine pollution involves the input of organic matter and nutrients. Organic matter and nutrients are not in themselves harmful, but can cause pollution problems when the inputs are excessive. There are a number of sources from which they enter the ocean. One of these is sewage, in the narrow sense of the waterborne disposal of human faeces and urine. Given the origin of sewage in this narrow sense, inputs of human pathogens are unavoidably bound up with sewage inputs. It is convenient therefore to consider issues of waterborne pathogens alongside nutrients.

8.2 The effects of organic matter

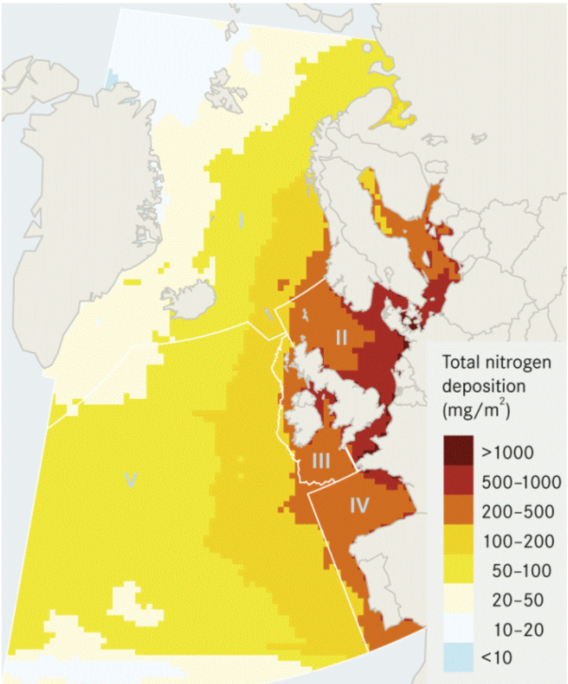
Sewage, in the narrow sense described above, contains high levels of organic matter, both particulate and dissolved. In a broader sense, the terms “sewage” and “municipal waste water” are used to describe the mix of waterborne disposal of human waste and discharges from artisanal and industrial undertakings when these are processed together. Organic matter also enters riverine discharges from natural sources, from direct or riverine inputs of industry and from aquaculture. Many artisanal or industrial discharges also contain high levels of organic matter, both particulate and dissolved. All this particulate and dissolved organic matter tends either to be oxidised or broken down by bacteria. Both processes require oxygen. The need for oxygen for chemical oxidisation is the Chemical Oxygen Demand (COD). The oxygen needed by the bacteria is the Biological Oxygen Demand (BOD). When the COD and BOD in a body of water exceed the oxygen available, the body of water can become hypoxic or anoxic, with a reduced ability to support aquatic life (Metcalfe & Eddy, 2004).

8.3 *The effects of nutrients*

Several nutrients are significant for the marine environment: mainly compounds of nitrogen, phosphorus, silicon and iron. In much of the ocean, primary production is limited by the availability of nitrogen. The inputs of nitrogen compounds are therefore of greatest significance. However, other aspects of nutrient input are also important: changes in the balance between available nitrogen and phosphorus can be the cause of blooms of various species of algae. Some species of algae produce toxins which can lead to amnesic shellfish poisoning, neurotoxic shellfish poisoning and paralytic shellfish poisoning (which can have death rates of 10 per cent-20 per cent) (GESAMP, 2001).

Anthropogenic inputs of nitrogen and phosphorus into estuarial and coastal ecosystems have more than doubled in the last century. These inputs are made through both the waterborne routes described above, but also significantly through airborne inputs, particularly in the forms of oxidized nitrogen, ammonia (especially from livestock), and water-soluble organic nitrogen. The importance of this airborne route for problems of the marine environment can be seen from the statistics for the North Sea and the Celtic Sea in the North-East Atlantic. In 2005 the total amounts of nitrogen estimated to be discharged in liquid discharges (riverine and direct) into these areas was 1,205 kilotons. These discharges came from 11 of the 15 States in the North-East Atlantic catchments. If we look at the airborne emissions of nitrogen from these 15 States, we find that these are estimated at 4,600 kilotons – 47 per cent from agriculture, 28 per cent from transport (including shipping), 21 per cent from combustion, and 3 per cent from other sources (OSPAR, 2010). These 4,600 kilotons of emissions are from a larger area (the total area of 15 States rather than the catchments in those States that discharge into the North-East Atlantic). Some will therefore be carried to sea areas other than the North Sea and the Celtic Sea, and some are already included in the 1,205 kilotons of riverine and direct inputs, since they will fall on land in the catchments of the North Sea and Celtic Sea. Nevertheless, it is clear that consideration of managing excessive inputs of nutrients must take into account the nutrients that reach the sea through the atmospheric transport of nutrients.

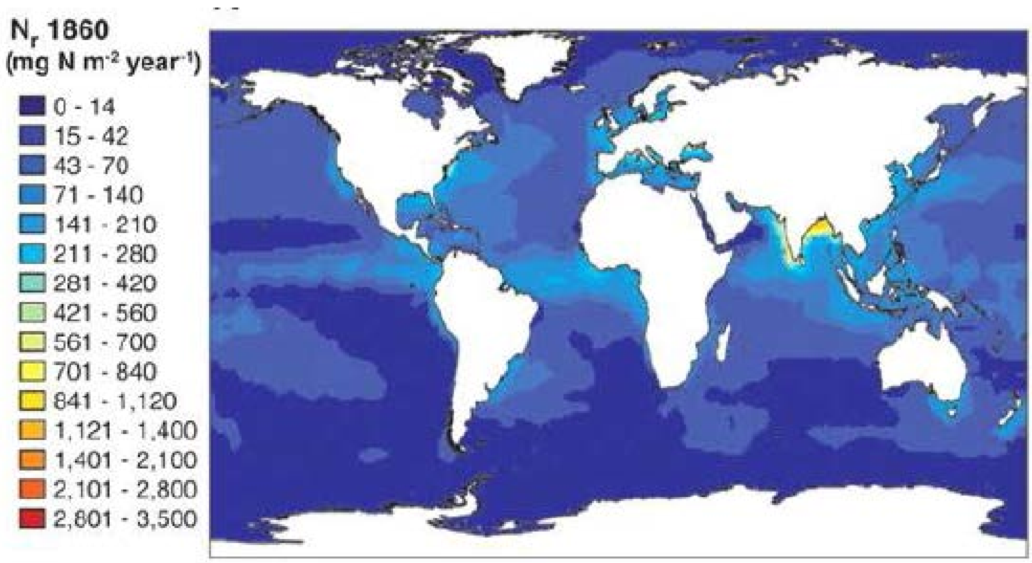
Atmospheric transport of nutrients is also important for the range over which the nutrients can be carried. As an example, the adjacent map shows the spread of nitrogen inputs to the North-East Atlantic from North-Western Europe in 2006: the inputs reach well into the open ocean (the area marked V on the map).



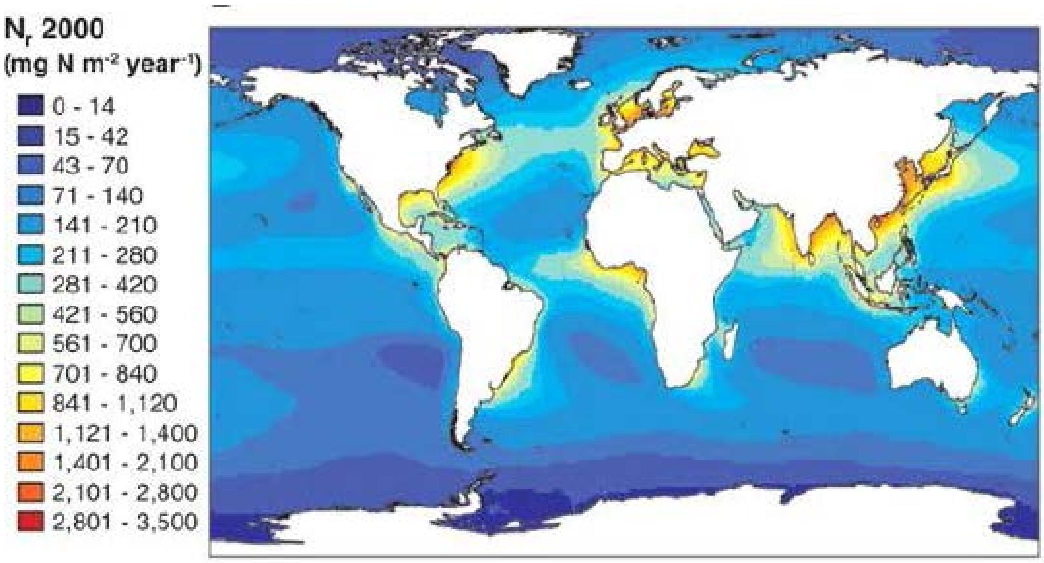
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 6. Atmospheric Transport of Nitrogen to the North-East Atlantic from North-West Europe. Source: EMEP model in OSPAR, 2010.

At the global level, the scale of the problem can be grasped from studies aimed at showing the implications of the secular trends in airborne inputs of nitrogen to the world ocean. Drawing on work by Galloway and others (Galloway et al., 1995) and Ducklow (Ducklow, 1996), Duce and others have demonstrated the increases in the inputs of total atmospheric reactive nitrogen (N_r) over the last 140 years (Figure 7). This brings out the significance of urbanization and industrialization and of intensified agriculture.



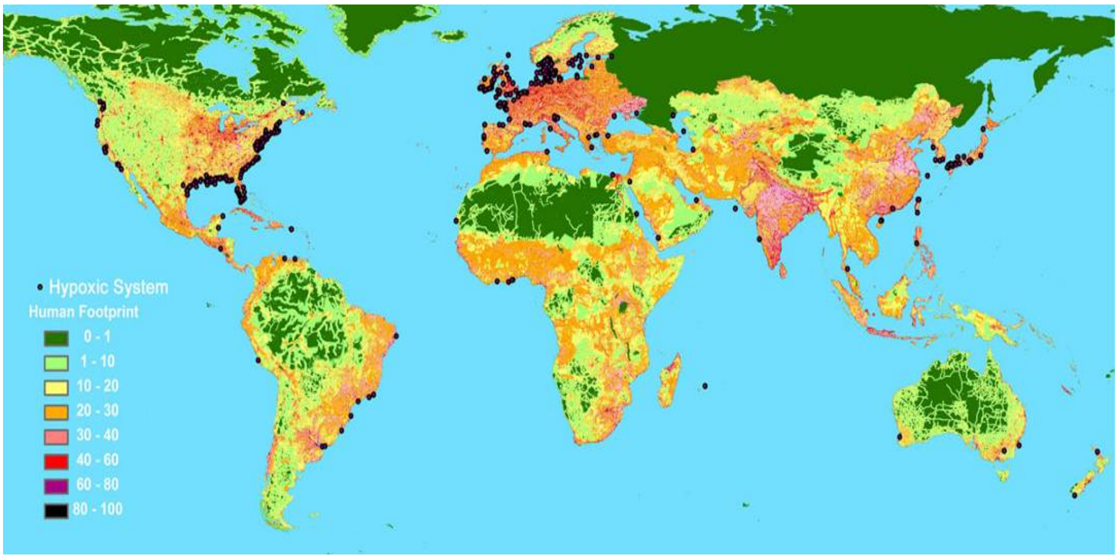
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 7. Airborne Reactive Nitrogen Inputs 1860 and 2000. Source: Duce et al., 2008. Total atmospheric reactive nitrogen (N_r) deposition to the ocean in mg per square metre per year in 1860 and 2000. Both organic and inorganic forms of nitrogen are included.

Inputs of nitrogen and phosphorus to the ocean provide nutrients to marine plants – especially to phytoplankton. Increased inputs stimulate growth (unless there is some countervailing factor, such as turbidity to reduce the availability of the light needed for photosynthesis). Excessive net phytoplankton production in coastal and shelf ecosystems can lead to an accumulation of phytoplankton biomass and to eutrophication problems. Among other phenomena, excessive net production of phytoplankton can result in *marées vertes* ("green tides") and red tides, when large areas of sea are infested with algae. Eventually, primary production will tail off as nutrients are exhausted and again growth is limited. The masses of algae (phytoplankton) will decay under the action of bacteria. This process will use up the oxygen dissolved in the seawater, and the resulting hypoxic (where oxygen is below 2 mg per litre) or anoxic (absence of oxygen) conditions will result in the death of the animals on the seabed and of fish that cannot leave the area. In the worst cases, these conditions will lead to "dead zones" (Diaz et al., 2008), loss of sea grass beds (Orth et al., 2006)), and increases in the occurrence of toxic phytoplankton blooms (Heisler et al., 2008). These dead zones reduce the amount of habitat available to aerobic animals upon which fisheries depend. The number of low-oxygen zones in coastal waters has increased exponentially to over 400 systems since the 1960s and has reached an area of about 245,000 km^2 worldwide (Figure 8; Rabalais et al., 2001; Diaz et al., 2008).



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 8. Global Map of Dead and Hypoxic Zones. Source: http://www.scientificamerican.com/media/inline/2008-08-15_bigMap.jpg.

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The occurrence of stratification, where different layers in the sea do not mix, can be significant for problems from nutrients, since concentrations of nutrients may be much higher in one layer as a result of the water inputs having a different density. Since stratification is often seasonal, problems from nutrients can often also be seasonal. Significant seasonal meteorological changes (such as the monsoons, rainy seasons or changes in insolation (the amount of sunlight)) can also create seasonal problems from nutrients through changes in runoff and primary production.

At the same time, even high levels of nutrients in discharges to the seas do not necessarily create problems: in estuaries and coastal lagoons, depending on local circumstances, bacterial action can result in a net conversion of nitrates from land runoff into nitrogen gas released to the air, thus reducing the load to the sea. Also, the turbidity of coastal water, resulting from tidal disturbance of sediments and/or coastal erosion and other causes, can limit the depth to which sunlight can penetrate and thus inhibit photosynthesis and the growth of phytoplankton. The precise consequences of heavy loads of nutrients in discharges to the sea will therefore often depend on local circumstances, including the rate at which semi-enclosed areas are flushed by tides and currents.

In certain circumstances, anoxic zones occur naturally (Helly and Levin, 2004). In the Black Sea, the large inflows of fresh water from rivers such as the Danube, Don and Dnieper result in a high degree of stratification, with little mixing between the layers. The result is that a large part of the central deep water of the Black Sea (estimated at about 90 per cent of its volume) is naturally anoxic (Heileman et al., 2008c). Likewise, where narrow continental shelves and currents flowing from the open ocean against the continental slopes are found, nutrient-rich, oxygen-poor water can be brought up into coastal waters, and produce hypoxic or even anoxic conditions. Examples of this are found on the western coasts of America immediately north and south of the equator, the western coast of sub-Saharan Africa, and the western coast of the Indian sub-continent (Chan et al., 2008).

8.4 Sources of nutrients

8.4.1 Municipal waste-water

Urban settlements have, of course, always produced waste-water, but a steep change in the quantities and their effect on the environment occurred from the middle of the 19th century, with the introduction of waterborne methods of disposing of human excrement and their connection to collective drains. Until then, the main system of disposal had been cess-pits and the collection of "night soil" in carts and its disposal on land for use as agricultural fertilizer. The first major changeover came in England in 1848, when legislation made the use of sewers for disposal of human excrement compulsory as a measure against cholera. Within ten years, some of the problems that the new approach could cause were shown by the Great Thames Stink of 1858, which, among other things, made the newly built Houses of Parliament almost unusable: the decomposition of the waterborne excrement produced intolerable levels of stinking gas. Sewage treatment for waste-water discharges to inland waters was adopted as the solution, and sewage treatment processes gradually improved in effectiveness and spread to more and more parts of the world.

The idea that treatment of waste-water discharges direct to the sea was also essential took much longer to be accepted: as late as 1990, some large towns in Western Europe still discharged major parts of their municipal waste-water untreated direct to the sea. The belief that the ocean had an almost unlimited absorptive capacity of the ocean was difficult to eradicate. However, the problems resulting from municipal waste-water discharges to relatively enclosed bays and harbours were acknowledged early - in the United Kingdom, the problems of the semi-enclosed Belfast Lough were one of the reasons for the investigations of the 1896 Royal Commission on Sewage Disposal, which established ground-breaking standards for sewage treatment, in terms of suspended solids and BOD per unit volume of discharge. However, it took the recognition of the significance of the problems from nutrients in relatively open sea areas such as Chesapeake Bay or the German Bight in the 1980s to create more general acceptance that action was needed, and to draw attention more generally to the issue of nutrient inputs to the sea.

The main routes of nutrient input are through rivers and direct discharges through pipelines of waste-water from sewage-collection systems and factories. When the Global Programme of Action for the Protection of the Marine Environment (GPA) was adopted in 1995, there was general agreement that the most important need for protecting the marine environment and improving human well-being was improved management of sewage, especially that from large conurbations. Where sewage treatment is applied to sewage discharges, three levels of treatment are typically recognized: primary (removal of solids and floating oil and grease), secondary (breaking-down of biological substances by microbes or protozoa) and tertiary (disinfection and removal of nutrients). It is not always essential for discharges from sewage-collection systems to be treated before discharge. In some circumstances, very long discharge pipelines can take untreated sewage sufficiently far out to sea, and into sufficiently dynamically active waters, that the nutrients and microbes in the sewage are adequately dispersed and assimilated and problems of eutrophication avoided. For this to be the case, the pipelines must take the sewage well beyond immediate coastal waters and strong currents must be present to provide the dispersal. Even then, in most cases, at least primary treatment of the sewage is preferable. Progress has been made in many parts of the world but, overall, untreated sewage inputs remain a major threat to the marine environment.

Increasingly, in addition, inputs of water across the coastline through underground aquifers are being recognized as a significant pollution route, although statistical estimates of the amounts of water, nutrients and contaminants through this route are rarely available.

8.4.2 Food and related industries

The preparation of human food inevitably results in the generation of organic waste: milling grain produces chaff; brewing and distilling produce the spent malt or other grain used; wine-making leaves the pressed grapes; fish preparation leaves guts, heads and tails, and so on. Some of these wastes are liquid or semi-liquid and can be discharged to the sea. Others can conveniently be disposed of into the sea (especially the waste from fish-processing), directly or through a watercourse. As explained in chapter 12, aquaculture is also a source of nutrients to the marine environment. All these elements will create BOD or COD, and will release nutrients as they are decomposed or oxidized.

8.4.3 Land runoff

The world has been able to produce more and more food from land, through a combination of improvements in strains of crops, agricultural techniques and pesticides, increased use of fertilizers, as well as bringing new areas into cultivation. The scale of this increase in agricultural production can be seen from FAO statistics on cereal production: an increase of over 25 per cent in the tonnage of cereals produced worldwide between 2002 and 2012. This increase in overall tonnage is also reflected in increased yield per hectare: over the period 2002 to 2012, yields increased by over 7 per cent in southern Asia, by over 9 per cent in eastern and south-eastern Asia, by over 18 per cent in Africa and by over 20 per cent in western Asia.

The substantial increases in total crops and in yield, while essential to feed the world's growing population, carry with them some environmental problems for the marine environment. As discussed above, some of the pesticides used on land have had impacts on the marine environment as a result of runoff. Likewise, the increased use of fertilizers has resulted in increased runoff of nutrients to the seas. These nutrients, intended to promote photosynthesis in land plants, also encourage primary production in the seas, and result in eutrophication problems. The runoff not only takes the obvious form of surface water entering the sea through rivers and watercourses, it can also enter the sea through groundwater seepage through aquifers. Estimates suggest that direct subterranean/submarine discharges of fresh water to the oceans around the world deliver up to 12 per cent of total surface water runoff, with the most accepted values between 5 per cent and 10 per cent (Basterretxea et al., 2010).

The use of nitrogen-based fertilizers has grown enormously in recent decades. This growth continues, as Table 4 shows: world consumption has increased by 42 per cent between 2002 and 2012, including more than doubling in Latin America, southern Asia, eastern Asia and Oceania.

Table 4. World Nitrogen Fertilizer Consumption

Million tons

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Europe and Central Asia	**5,330**	**5,090**	**5,743**	**5,798**	**5,705**	**6,699**	**6,902**	**6,711**	**6,559**	**6,997**	**7,174**
North America	**2,736**	**2,620**	**2,715**	**3,150**	**2,763**	**3,151**	**2,884**	**2,466**	**2,685**	**2,868**	**2,959**
Latin America	**691**	**722**	**865**	**880**	**1,043**	**1,253**	**1,106**	**1,091**	**1,277**	**1,455**	**1,459**
Africa	**800**	**920**	**1,112**	**1,160**	**1,022**	**990**	**1,013**	**1,017**	**1,054**	**1,067**	**1,142**
West Asia	**409**	**462**	**547**	**533**	**441**	**440**	**456**	**595**	**550**	**455**	**417**
South Asia	**99**	**96**	**137**	**164**	**141**	**138**	**167**	**197**	**210**	**232**	**238**
East Asia	**908**	**1,199**	**1,275**	**1,315**	**1,391**	**1,490**	**1,671**	**1,428**	**1,692**	**1,737**	**1,962**
Oceania	**161**	**372**	**378**	**462**	**389**	**422**	**468**	**531**	**544**	**556**	**679**
World	**11,295**	**11,779**	**12,775**	**13,473**	**12,901**	**14,583**	**14,665**	**14,045**	**14,578**	**15,374**	**16,030**

Source: FAOSTAT.

Increased use of agricultural fertilizers does not necessarily result in increased nutrient inputs to the seas: good agricultural practices can help avoid this. Adjusting amounts of fertilizer applied to likely take-up by crops, applying fertilizers at the time of year when take-up by crops will be greatest, ploughing so that the furrows do not promote runoff, and leaving buffer zones along watercourses can all help reduce the leaching of nutrients to the watercourses and the seas.

The type of crop cultivated can also be very significant. Legumes, such as soya beans, naturally fix nitrogen from the air into soil, from where it can then run off. The vast increases in soya bean cultivation in some tropical countries (such as Brazil) can increase nitrogen fluxes in the same way as the use of nitrogen fertilizers (Filoso et al., 2006).

Intensive raising of livestock is another major source of nutrients: both solid and liquid wastes are involved, as well as gaseous emissions of ammonia and methane, all of which can find their way to the seas through runoff from the land or deposition from the air.

8.4.4 Other sources of nutrients

The processing of many food products by food and drink industries for consumption also frequently results in waste-water containing nutrients in various forms. These waste-water streams are a further factor affecting nutrient inputs to the seas.

The combustion of petrol/gasoline and other liquid fuels also produces nitrogen compounds, which can be carried through the air to the seas. Vehicles powered by internal-combustion engines are obvious sources of such compounds (especially of ammonia). Near major shipping routes, the contribution from ships can also be significant. In north-western Europe, for example, over 25 per cent of nitrogen emissions to the atmosphere are from these sources (OSPAR, 2010).

8.5 Waterborne pathogens

Untreated municipal waste-water inevitably contains infectious microbes from humans. If these microbes reach the seas, they can infect humans both when they immerse themselves in sea water (sea-bathing) and through the consumption of fish and shellfish (especially the latter, since shellfish filter large quantities of seawater in the course of obtaining their food). Similar contamination also arises from animal excrement. In bathing waters, the probability of respiratory and intestinal diseases and infections rises for bathers rises in an almost direct relationship with the sewage pollution in the water. GESAMP and the World Health Organization estimated in 1999 that bathing in polluted seas causes some 250 million cases a year of gastroenteritis and upper respiratory disease. The same study estimated that eating contaminated shellfish is responsible for the loss every year of 3,500,000-7,000,000 disability-adjusted life-years (a standard measure of time lost due to premature death and time spent disabled by disease), putting it in the same bracket as stomach cancer, intestinal nematodes and upper respiratory tract infections (GESAMP, 2001).

9. Regional view of impacts of Nutrients and Waterborne Pathogens

The foregoing review of the sources of oxygen demand (both COD and BOD), nutrients and waterborne pathogens and the ways in which they can affect the ocean sets out the general mechanisms. It is necessary then to see to what extent the various parts of the ocean have in fact been affected. Because this kind of problem is confined to coastal waters (since distribution and dilution remove the detrimental effects), it is not necessary to examine the open ocean area.

9.1 Arctic Ocean

No problems are reported from elevated levels of nutrients in the Arctic Ocean because there are no major concentrations of population or agriculture.

9.2 Atlantic Ocean and Adjacent Seas

9.2.1 North-East Atlantic, North Sea and Celtic Seas

Serious problems from eutrophication became apparent in the North Sea in the 1980s, as dead zones appeared, particularly in the German Bight. As a result, the coastal States committed themselves to a 50 per cent reduction in inputs of nitrogen and phosphorus compounds by 1995. The 1998 OSPAR Eutrophication Strategy extended the goals of combating eutrophication to the whole of the North-East Atlantic. In 1991, the European Union adopted legislation requiring improved treatment of urban waste-water and reduction in inputs of nitrates from agriculture. Assessing the impacts of anthropogenic nutrient inputs (especially inputs from diffuse sources) is complicated by the delivery of nutrient-rich water from the deep Atlantic. Most North Sea countries achieved the target reduction in phosphorus inputs by 1995, and some countries have now reduced phosphorus inputs to 15 per cent or less of their 1985 level. Although the target for 50 per cent reductions in nitrogen inputs between 1985 and 1995 was not achieved (and still has not been achieved, except in Denmark), the resulting major programmes have achieved substantial reductions in inputs. Germany and the Netherlands have almost achieved the 50 per cent reduction. Even after these reductions, eutrophication problem areas, with enhanced levels of nutrients, are still found along the coasts of Belgium, Demark, Germany and the Netherlands, while a number of estuaries and fjords in Ireland, Norway, Portugal, Spain and the United Kingdom also show such levels and are therefore regarded as eutrophication problem areas. In France, the estuaries of the Loire and Seine and much of the coast of Brittany (where beaches covered in sea-lettuce create serious health impacts on both locals and tourists) are still eutrophication problem areas. Mass mortality of benthic and pelagic animals has, however, been limited to a few estuaries and fjords in Denmark, the Netherlands, Norway and Sweden (OSPAR, 2010).

Since 1976, the European Union has had programmes to reduce the inputs of waterborne pathogens to the waters of its member States. This has required major investment in sewage treatment and the management of storm-water runoff. The results have been a steady improvement in water quality, both for bathing and for shell-fish production. By 2012 (which was a very wet summer in Europe) with consequential high levels of storm runoff), only 1.7 per cent of the monitored coastal bathing sites failed to meet the European Union’s mandatory standards. Most of these were in the North Sea (EEA, 2013).

9.2.2 Baltic Sea

The Baltic Sea is sensitive to eutrophication because of the strong halocline, the limited water exchange with the North Sea and the consequent long residence time of water in it. High nutrient loads and a long residence time mean that nutrients discharged to the sea will remain in the basin for a long time. In addition, the stratification of the water masses increases the vulnerability of the Baltic Sea to eutrophication, because it hinders or prevents ventilation and oxygenation of the bottom waters and sediments. Furthermore, absence, or low levels, of oxygen worsen the situation by affecting nutrient transformation processes by bacteria, such as nitrification and denitrification and the capacity of sediments to bind phosphorus, and lead to release of significant quantities of it.

As a result, most of the Baltic is regarded as suffering from problems of eutrophication. Only the Gulf of Bothnia (the northernmost part of the waters between Finland and Sweden) is generally free of these problems, although even here, there are small coastal sites with pronounced eutrophication problems. The worst affected areas are the Gulf of Finland, the Gulf of Riga, the Baltic Proper (the area between Sweden and Estonia and Latvia), the area east of the island of Bornholm, the Belts and the Kattegat. Smaller sites on the coasts of Sweden and the Gdansk Bight are also classified as suffering eutrophication (HELCOM, 2010a). In general, the anoxic and hypoxic areas of the Baltic Sea are regarded as one of the largest areas of dead zones in the world.

9.2.3 Mediterranean Sea

Eutrophication is assessed as being a localized problem in the Mediterranean basin. The main causes, as elsewhere, are inadequately treated sewage and runoff and emissions from animal husbandry and high usage levels of agricultural fertilizers. 37 per cent of coastal towns with a population of more than 2,000 have no sewage treatment at all, and a further 12 per cent have only primary treatment. These towns are concentrated on the southern shore of the western Mediterranean, in coastal Sicily, on the eastern coast of the Adriatic and in the Aegean and the north-eastern corner of the Levantine basin. Fertilizer usage reaches over 200 kg per hectare of arable land in Croatia, Egypt, Israel and Slovenia, and is over 100 kg per hectare in France, Greece, Italy and Spain. Since the eastern Mediterranean is naturally oligotrophic, locally enhanced levels of nutrient input can produce marked results. The main hypoxic area is along the delta of the River Nile (Egypt) and there are areas at high risk of hypoxia at the mouth of the River Po (Italy) and the River Rhône (France). Medium risks of hypoxia have been reported at the mouth of the River Ebro (Spain) and in the Gulf of Gabès (Tunisia), the Gulf of Sidra (Libya), some bays and estuaries around the Aegean Sea and the Gulf of Iskenderun (Turkey), although Turkish authorities indicated that risks of hypoxia have not been confirmed in the latter area (UNEP, 2012).

9.2.4 Black Sea

As noted above, the Black Sea has historically had an anoxic zone in deep waters below 200 m. However, a major hypoxic (and, at times, anoxic) zone developed in the shallower north-western shelf from the 1950s. The inputs of nutrients by 1990 were estimated at approximately 80 per cent from agriculture and 15 per cent from municipal waste-water (most large towns having at least secondary sewage treatment). Between 1960 and 1990 the nutrient input into the catchments of the Rivers Danube, Dnipro and Don increased approximately 10-fold. The resulting anoxic or hypoxic zones at their peak in 1983-1990 extended to between 18,000 and 40,000 square kilometres, with consequential effects on fisheries and benthic biodiversity.

Three causes reduced the massive agricultural inputs: the economic problems of Eastern Europe from 1990 onwards, the adoption of stringent standards for nitrate emissions by the European Union (which required changes in the practices of States in the upper Danube basin) and the preparation for the entry of some States in the lower Danube basin into the European Union (which required the adoption of those standards). The very substantial reductions in the nutrient inputs meant that the worst effects of the hypoxia had disappeared by 1995, although the effects of changes in benthic biodiversity are still being felt (Borysova et al., 2005; Diaz et al., 2008).

9.2.5 North-West Atlantic

Nitrogen releases to air and water are low in most of Canada, but southern areas where rapid development is taking place show signs of emerging problems. At present, there is little sign of estuarine eutrophication on the Atlantic coast of Canada, but hypoxic conditions have been found in the lower St Lawrence estuary areas since the mid-1980s. These are at depths below 275 m. About a third of the problem is attributed to land-based inputs. The other two-thirds seem to be the result of changed oceanic circulation, resulting in larger amounts of Atlantic water from south of the Gulf Stream entering the estuary. This water has lower oxygen levels and a higher temperature (resulting in more bacteriological activity and consequent consumption of oxygen) than the previously dominant Labrador Current water (Schindler et al., 2006; DFO-MPO, 2013).

The United States National Coastal Condition Report (NCCR) uses a measure of water quality relevant to the occurrence of eutrophication based on a combination of levels of dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), chlorophyll a, dissolved oxygen and the degree of water clarity. Cut-off points (varying between regions) are used to classify these indicators into good, fair and poor categories, and an algorithm gives an overall value in the light of these classifications (EPA, 2012). The United States has also carried out a National Estuarine Eutrophication Assessment (NEEA), looking at 141 estuaries in the contiguous 48 states. An update was published in 2007. Although full conclusions could be reached on only 64 of the estuaries, 29 showed moderately high to high eutrophic conditions (NEEA, 2007).

For the North-East Region (Maine to Virginia, including Chesapeake Bay), there is a marked gradient from north to south: the overall evaluation is that the region has fair water quality, but this ranges from very good quality in the open estuaries of the north, to poor in many of the southern estuaries, which have poor levels of water exchange and drain densely populated catchments. Particular problem areas are Great Bay (New Hampshire), Narragansett Bay (Rhode Island), Long Island Sound (between Connecticut and Long Island, New York), New York/New Jersey (NY/NJ) harbour, the Delaware Estuary, and the western tributaries of Chesapeake Bay. High levels of enteric bacteria resulted in advice for short periods in the mid-2000s against bathing at about 17 per cent of the beaches monitored. Further out to sea, the water quality in the Mid-Atlantic Bight was generally rated as "good" (EPA, 2012). The NEEA showed a similar division between the estuaries in the northern and southern parts of this region, with the former being generally good and the latter generally showing the worst conditions nationally. It also noted a worsening between 1999 and 2004 in the status of 8 of the 22 estuaries assessed in the southern part (NEEA, 2007).

Chesapeake Bay presents a complex of problems, in part because of its large catchment basin with extensive industrial agriculture and a large and rapidly growing population, and in part because of the long residence time of water in the estuarine system (measured in months) (Kemp et al., 2005). Efforts to address the problems began in 1983 with the Environmental Protection Agency's Chesapeake Bay Program. By the mid-1990s, this seemed to be bearing fruit, but by 2005 it was clear that it was not reaching its goals (GAO, 2005). New efforts began in 2009, focused on a range of measures to address the multiple causes of the problems, including measures to achieve by 2025 a specified total maximum daily load from all sources of nitrogen and phosphorus (Chesapeake Bay Program, 2014).

For the South-East Region (North Carolina to Florida), the overall rating was that the water quality was "fair", with only 22 per cent of the sampling points rated "good" and 13 per cent "poor". The main problem areas were the large estuaries of Albemarle and Pamlico Sounds (North Carolina) and the major ports of Charleston (South Carolina) and Savannah (Georgia). Away from the immediate coast, the South Atlantic Bight was regarded as having overwhelmingly "good" water quality (EPA, 2012). This picture is generally consistent with the NEEA, but that assessment was unable to classify the Albemarle and Pamlico Sounds, while judging the Charleston and Savannah port areas as presenting lesser problems (NEEA, 2007).

9.2.6 Wider Caribbean

The water quality of the waters of the Gulf Coast of the United States along the immediate shoreline is judged by the National Coastal Condition Report to be "fair", with 30 per cent of the sampling stations "good" and 10 per cent "poor" (and 7 per cent not evaluated because of lack of data) (EPA, 2012). This picture was consistent with that presented by the NEEA (NEEA, 2007).

However, a little further out into the shelf waters, there is a major eutrophication problem area. Since 2000 this dead zone has fluctuated annually in size from about 8,500 sq km to about 21,750 sq km (NOAA, 2013). This is regarded as the second-largest dead zone in the world. The reasons for the fluctuation are not fully understood, but are largely connected with the levels of flow in the Mississippi River. This drains about 3.1 million sq km (about 40 per cent of the contiguous United States), with a very high level of arable and livestock agriculture and a correspondingly high level of nitrogen and phosphorus runoff. The first problems were noted by shrimp fishermen in the 1950s. Studies of the sediments show that algal growth (and hence eutrophication problems) in the area of the dead zone increased significantly in the second half of the 20th century. The dead zone has had a significant effect on the shrimp fishery (Turner et al., 2008; Rabalais et al., 2001; Diaz et al., 2008).

In other parts of the wider Caribbean, significant progress has been made in addressing the problems of sewage and other nutrient discharges. In 2010, the Caribbean Environment Programme conducted a comprehensive survey of the problems. In spite of some uncertainties, this showed major progress in Colombia and Venezuela in reducing inputs from municipal waste-water since an earlier survey in 1994: total nitrogen inputs had reduced by more than 80 per cent, and also substantial reductions in organic matter (BOD). Elsewhere, smaller reductions had been achieved in mainland States, but large increases were found in the island States. Much more general progress had been made in reducing organic matter (BOD) and nutrients from industrial sites in coastal areas: reductions of 50 per cent-90 per cent in the former in all parts, and 90 per cent or more in the latter everywhere except in the United States and Mexico (UNEP-UCR/CEP, 2010).

Nevertheless, there are major issues with sewage, both in terms of health and eutrophication. The Caribbean relies heavily on the tourist industry for its economic well-being. Clean bathing waters and coral reefs are two important supports for that tourist industry. Eutrophication leads to excessive algal growth which can smother and kill corals – especially if the herbivore fish (such as groupers) have been reduced by over-fishing. Untreated sewage harms the health of both local populations and visiting tourists. Both effects have serious implications for the tourist industry.

9.2.7 South-East Atlantic

Detailed studies and analysis conducted in the Guinea Current region, and more generally in West and Central Africa, show that sewage constitutes the main source of pollution in that area from land-based activities. A similar situation applied in the regions of the Benguela Current (where harmful algal blooms also appear to be on the increase) and the Canaries Current (where the waters off the cities of Dakar in Senegal and Casablanca and Rabat in Morocco appear to be specially affected). All the countries assessed reflect high urban, domestic loads, sometimes from industrial origin, which create problems from BOD, suspended sediments, nutrients, bacteria and pathogens. For example, the mean annual amount of oxygen required to meet BOD for the entire West and Central Africa region, including the countries adjoining the Guinea Current, has been estimated to be 288,961 tons for BOD from municipal sewage and 47,269 tons for BOD from industrial discharges: a total of 336,230 tons (For comparison, the mean annual amount of oxygen required to meet BOD for the River Rhine at the border between Germany and the Netherlands is about 60,000 tons.). Again, the rapid growth of urban populations is far beyond the capacity of relevant authorities and municipalities to provide adequate basic services of sewage and waste-water-treatment facilities (GCLMEP, 2003; Heileman, 2008b).

9.2.8 South-West Atlantic

The waters off the northern coasts of Brazil have naturally relatively low levels of nutrients. During most of the year, therefore, there are no problems from eutrophication. However, during the rainy season, runoff from land brings sudden increases in the levels of nutrients, and consequently algal blooms then occur (de Lacerda et al., 2002). Estuaries, bays and lagoons close to the larger conurbations tend to show eutrophication from sewage and other nutrient inputs, often enhanced by the effects of limited water circulation (Costa, 2007).

Further south, in the heavily populated areas of south-eastern Brazil, high levels of nutrients and consequent eutrophication problems are common. Guanabara Bay (on which the city of Rio de Janeiro (population 6.3 million) is located) is the most heavily affected area, with very high nutrient levels and high levels of microbial pollution (de Lacerda et al., 2002). In the south of Brazil, in the State of Santa Catarina, in urban estuaries, the dissolved inorganic nitrogen (DIN) was generally three times greater than in non-urban ones (Pagliosa et al., 2006).

In Brazil, the majority of households and industries generally do not have access to sewerage. The national average of those with connections to a sewer in 2008 was 44 per cent, ranging from 1.7 per cent in the State of Pará in the north, to 82 per cent in the State of São Paulo in the south. Supply of piped water was much more common than sewerage connections, and sewerage connections were more common than sewage treatment: only 28 per cent of the volume of water supplied passed into the sewer system and only 68 per cent of the sewage was treated, only a little over half of that treated receiving secondary or higher treatment. This situation in 2008, however, represented a big improvement (for example, an increase of 40 per cent of households connected) on that at the time of the previous survey in 2000. Brazil currently has a major programme of investment (equivalent to 4.2 billion United States dollars) for the improvement of sanitation. So it is reasonable to hope that the situation will improve (IBGA, 2008; PAC2, 2014). Further south again, Uruguay and Argentina, which contain the large conurbations of Montevideo and Buenos Aires, have serious microbial pollution in some localized areas of their coastal waters, where pathogens have been detected which in some cases have exceeded international recommended levels for recreational water. Toxic red tides are becoming more frequent and of longer duration (Heileman, 2008e).

9.3 Indian Ocean

9.3.1 Western Indian Ocean

Throughout this area, there is a tendency for high nutrient levels to encourage ecosystem change, leading to dominance by algal communities. On the coasts of the Agulhas Current, the growing coastal populations and increasing tourism, for which sewage treatment facilities are inadequate, result in the increasing discharge of raw sewage directly into rivers or the sea, leading to eutrophication in localized areas. Untreated effluents from fish processing plants and abattoirs are also frequently discharged into the sea, causing varying degrees of localized pollution.

On the coasts of the States bordering the Somali current, most of the coastal municipalities do not have the capacity to handle the vast quantities of sewage and solid wastes generated daily. Raw sewage containing organic materials, nutrients, suspended solids, parasitic worms and benign and pathogenic bacteria and viruses is discharged into coastal areas. High microbial levels are observed in areas near sewage outfalls (Heileman and Scott, 2008).

In the Comoros, there is no sewerage, drainage or waste-water treatment. In Kenya, microbial water quality studies have been completed in a number of locations and microbial pollution levels near urban centres, such as Mombasa, were several orders of magnitude higher than in coastal waters in rural areas. In Mozambique, faecal coliform counts in the channel adjacent to the Infulene River in Maputo were found to be worryingly high. In Madagascar, similar high counts of bacteria from human excrement have been measured in coastal waters. Microbial pollution is an ongoing problem in several Mascarene coastal areas. Periodic draining of waste-water ponds on fish farms adds to nutrient discharges. At present, in Mauritius, 73 per cent of households use cesspits or septic tanks whilst 2 per cent use pit latrines; so most of the effluents are discharged directly to the sea or are carried to the sea by runoff and rivers with higher potential for microbial pollution, particularly after heavy rains. Agricultural practices in Mauritius (both intensive agriculture and small-scale market gardening, and livestock rearing) also pose a serious threat to coastal ecosystems and give rise to algal blooms and red tides (ASCLME/SWIOFP, 2012).

9.3.2 Red Sea, including the Gulf of Aden, the Gulf of Aqaba and the Gulf of Suez

Although its effects are usually limited to a small area around urban areas and large tourist developments, sewage is a major source of coastal contamination throughout the Red Sea and the Gulfs of Aden, Aqaba and Suez. Because of rapid population growth and inadequate treatment and disposal facilities, poorly treated or untreated sewage is dumped in coastal areas. Inputs of sewage also results in eutrophication of the coastal waters around some population centres, major ports and tourist facilities (Gerges, 2002).

9.3.3 Persian Gulf

The shortage of freshwater resources and the availability of financial resources resulted in an extensive investment in sewage treatment in the Gulf States on the southern shore of the Persian Gulf, in order to permit re-use of the treated water for irrigation and other purposes. The treatment applied is generally secondary or tertiary. This re-use also reduces the demand for water from desalinization. Hence there has not been the same pressure from discharge of nutrients as in other parts of the world from urban growth and consequent increases in urban waste-water. As long ago as 1999, 252 million cubic metres of water were being produced annually in this way (Alsharhan et al., 2001). The latest FAO figures show that this has risen to 551 million cubic metres/year. Elsewhere in the area, coastal water quality at the Iraq-Kuwait border has declined as a result of increased agricultural pollution due to the draining and subsequent loss of the filtering role of the Mesopotamian marshlands (Heileman et al., 2008b). On the northern shore, moreover, some cities, such as Bushehr, are discharging treated sewage effluent, which is giving rise to enhanced levels of nutrients, although it is not clear that this results in eutrophication problems (Rabbaniha et al., 2013).

9.3.4 Arabian Sea, including waters west of India, the Maldives and Sri Lanka

This area is affected by natural nutrient enrichment, at the time of the south-western monsoon, as deep-level nutrient-rich water is brought up onto the narrow continental shelf (Naqvi et al., 2009).

In the north of the area, sewage, fertilizers and other effluents have resulted in eutrophication in coastal areas such as Karachi. Fish kills in some localities, such as off the Karachi coast and Gawadar Bay, have been attributed to harmful algal blooms caused by the growing pollution (Heileman et al.,2008b).

Further south, the Indian Central Pollution Control Board (CPCB) estimates that the 644 cities and towns of over 50,000 population across the country (coastal and inland) discharge 5,500 megalitres a day of sewage, of which only 522 megalitres a day – less than a tenth – receives any treatment before discharge. Of this, the 120 cities and towns of populations of over 50,000 in the coastal area generate about 6,835 megalitres a day of waste-water, out of which only 1,492 megalitres (22 per cent) receive any treatment. The rest is discharged without any kind of treatment to the coastal waters. This represents an increase of about 150 per cent over the levels of discharge twenty years ago, although the rate of increase has recently slowed (CPCB, 2014). There have also been large increases in the amounts of artificial fertilizers used. However, it is argued that much of this usage is in relative dry areas from which there is little runoff (NIOT, 2014). Considering the west coast of India separately, the state of Maharashtra, in the middle, accounts for the majority of the 3,220 megalitres discharged daily into the Arabian Sea (CPCB, 2014). In spite of this heavy nutrient load, which produces some hypoxic zones, few eutrophication problems (such as harmful algal blooms) are reported, probably because of the very dynamic tidal action which produces rapid dispersal. The algal mass, measured as chlorophyll-a, is lower in this area than in the Bay of Bengal (BOBLME, India 2011).

Given the statistics on sewage, it is not surprising that high levels of pathogenic bacteria are reported all along the coast (except in the Karwar (Karnataka) region), with increasing levels on the coasts of Goa, the rest of Karnataka and Kerala. These increasing trends in levels of nutrients and waterborne pathogens point to the significant influence of sewage inputs (NIOT, 2014).

9.3.5 Waters east of India, the Maldives and Sri Lanka (Bay of Bengal, Andaman Sea, Malacca Strait)

In the waters to the east of the Indian subcontinent, hypoxic areas regularly occur along the coast, although severe eutrophication problems appear to be rare. These hypoxic areas are partly a natural situation brought about by enhancement of nutrient levels by the monsoon winds bringing nutrient-rich water to the surface (Vinayachandran, 2003), and partly by high levels of nutrient input from the land. The major inputs are from West Bengal in India (which provides well over 50 per cent of the inputs from the Indian coast) and from Bangladesh. The Indian input of sewage is around 2,330 megalitres/day into the Bay of Bengal, 80 per cent of which has had no treatment (CPCB, 2014). The hypoxic areas are also associated with frequent harmful algal blooms, for which seven hotspots have been identified (Gopalpur (Orissa), Visakhapatnam and Coringa (Andra Pradesh) and Ennore, Kalpakkam, Porto Nova, and the Gulf of Mannar (Tamil Nadu)) (BOBLEME, India 2011; Satpathy et al., 2013; NIOT, 2014). High levels of pathogenic bacteria are found all along the Indian coast of the Bay of Bengal (NIOT, 2014).

In Bangladesh, sewage collection and treatment exists only for one-third of Dacca (the capital), although investment is taking place to extend this and develop a sewerage system for the port city of Chittagong. Human wastes from most of the 150 million population are therefore liable, eventually, to find their way into the Bay of Bengal. Increasing amounts of artificial fertilizers are being used – imports rose by 2.3 times between 2003 and 2006 – but no data are available for inputs to the sea.

Harmful algal blooms are frequent, and have been linked to mass mortalities in shrimp farms. Information is lacking on illnesses linked to food from the sea, but is thought to be increasing in parallel to increasing marine pollution (BOBLME, Bangladesh, 2011).

In Myanmar, there seems to be no evidence of hypoxic zones linked to major population centres. Generally, seawater samples showed acceptable levels of nutrients and dissolved oxygen, although samples from the mouth of the Yangon (Rangoon) river showed increased levels of suspended solids and COD (BOBLME, Myanmar, 2011).

On the Andaman Sea coast of Thailand, little provision is made for sewage treatment of the human wastes from the massive tourist industry. In particular, at Patong (the main town of the tourist island of Phuket), sewage discharges are leading to elevated nutrient levels and algal blooms in December-February of most years. However, the Thai authorities have established a comprehensive marine water-quality monitoring system, which shows that around 90 per cent of the sampling stations on this coast are “fair” or better. The only station with badly deteriorated water quality is at the mouth of the Ranong River, on the border with Myanmar. A major algal bloom and fish kill took place on this coast in 2007, but it seems likely that this was due to unusual upwelling of nutrient-rich water from the deep ocean (BOBLME, Thailand, 2011).

Malaysia also has a long-standing marine water-quality monitoring system. On the basis of this Malaysia more recently developed a marine water-quality index. This brings together parameters for suspended solids, oxygen demand and microbes, together with those for heavy metals. For the coasts facing the Andaman Sea and the Straits of Malacca, this index shows that in 2012, of the 62 coastal monitoring stations in this area, 3 per cent were rated “excellent”, 10 per cent “good”, 79 per cent “moderate” and 8 per cent “poor”. Three of the five “poor” monitoring stations were near the port of Malacca and the other two were beaches apparently badly affected by oil pollution. Similar results were reported for estuarine and island monitoring stations (BOBLME, Malaysia, 2011).

9.3.6 Waters west of Australia

In general, the waters around Australia have naturally low levels of nutrients, since they are not affected by any marine current that can bring water with a high nutrient content to the coastal waters, and since much of the coast has limited land runoff because of the low rainfall. Blooms of toxic and nuisance algae, however, continue to be a problem in a number of the estuaries and in inshore waters along the western coast, with adverse impacts that include major events of fish mortality. When they occur, algal blooms in this region can cover large areas. In Western Australia, major nutrient and algal bloom problems have a long history in the Peel–Harvey Estuary, caused principally by nutrient pollution from upstream agricultural lands. Major works were undertaken to improve flushing of the estuary, but they seem to have brought only temporary relief (SE2011 Committee, 2011).

9.4 Pacific Ocean

9.4.1 Waters west of Canada and the mainland of the United States

The low population density and the small areas that are devoted to arable and livestock farming of Alaska as compared with the rest of the United States mean that problems of enhanced nutrient and microbiological inputs do not exist. The handful of sampling sites classified as "fair" rather than "good" from the point of view of water quality by the National Coast Condition Report are thought probably to be the result of so-far-unidentified natural factors rather than of human impact (EPA, 2012).

The west coast of Canada also does not show any problems of eutrophication or microbiological disease. However, there appear to be risks that such problems may develop near the border with the United States, where the main population centres and agriculture are found. This is the possible result of expanding human populations and intensifying agriculture in the lower Fraser Valley and Puget Sound (Schindler et al., 2006).

9.4.2 Waters west of Mexico, Guatemala, El Salvador, Honduras, Nicaragua and Costa Rica

In the coastal waters of these countries, waste-water discharges and agriculture runoff are the main sources of anthropogenic nutrient enrichment. Very little urban waste-water is treated: for example, in El Salvador, less than 3 per cent is treated (Romero Deras, 2013). Fertilizer consumption increased from 76 kilogrammes per hectare to about 131 kilogrammes per hectare between 1990 and 2001, and has continued to rise. Deforestation and associated increases in erosion and runoff also contribute to enhanced nutrient runoff. Eutrophication problems have been noted in the Gulf of Nicoya (Costa Rica), Jiquilisco Bay (El Salvador) and Corinto and El Realejo (Nicaragua). Harmful algal blooms associated with eutrophication have also been observed (Heileman, 2008d).

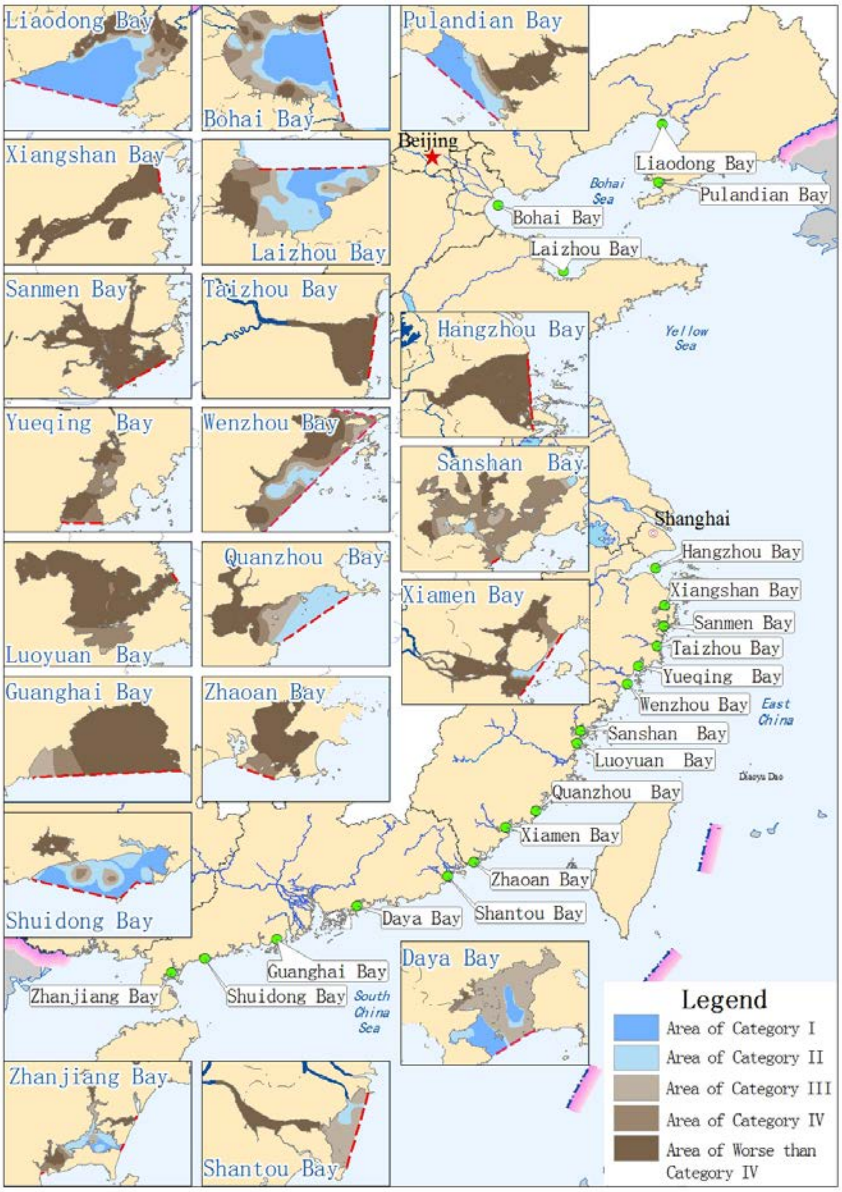
9.4.3 East Asian Coastal Seas – General

Both municipal waste-water and agricultural runoff present problems for the East Asian Seas. No consistent assessment is possible across the area as a whole, but it is clear that both these major sources are causing problems, particularly in the areas near the major conurbations. In the Philippines, Manila Harbour is a clear example of this. In Thailand, the national marine water-quality index shows that the main problem areas are in the inner Gulf of Thailand, around the mouths of the Chao Phraya, Thachin, Mae Klong, and Bangpakong Rivers. In Malaysia, the overwhelming majority of sampling stations on the east coast of the peninsula and in Sarawak, Sabah and Labuan were put into the "moderate" quality classification. The best areas are in the north of Sabah. Harmful algal blooms have become much more frequent in recent years in all parts of the region (UNEP/COBSEA 2009).

9.4.4 Coastal waters of China

The Chinese authorities have developed a water-quality assessment system which looks at the parameters related to (a) oxygen and nutrients (dissolved oxygen, COD, pH, inorganic nitrogen and phosphates), (b) heavy metals and (c) oil. Microbiological parameters are also monitored. Norms have been established for each of four categories (Category I: Clean water, Category II: Relatively clean water, Category III: Slightly polluted water, Category IV: Medium polluted water). Water that is worse than Category IV is classed as “Heavily polluted water”. Classifying waters, works on the “one out, all out” principle: if the samples from an area fail to meet the level specified for a category for any one of the parameters, then the area is demoted to a lower category. In practice, the determinant parameter for all areas is the parameter for inorganic nitrogen, except for Liaodong Bay (the north-eastern gulf of the Bohai Sea), where the determinant parameter is inorganic phosphate. Figure 9 shows the results in 2014 for studies in major bays along the coast of China: many are heavily polluted (the absence of indications seaward of the lines enclosing the bays, of course, does not mean that the water there is clean; merely that the data for such areas is not included in this map). The total area of waters that could not be classified as Category I (clean water) increased steeply, at about 20,000 square kilometres/year, from 1990 to 2000. Since then, the amount of water that is classified as other than clean has remained more stable, although the areas within the different categories below Category I have fluctuated. In particular, the total area classified as heavily polluted water (worse than Category IV) has remained more or less stable over the decade from 2000 to 2009. The fluctuations have, however, been different in the different areas. In the Bohai Sea, although the area of clean water has increased, the other areas have deteriorated in status. It should be remembered that about 10 per cent of the planet’s population live in the catchments of the Bohai Sea. In the Yellow Sea, the area in category II and worse increased by about 40 per cent between 2003 and 2004, but by 2009 had recovered its pre-2003 level. In the East China Sea, the area in Category I (clean water) increased until 2005, but after that point remained constant. In the South China Sea, the area of water in Categories II and worse increased by about 75 per cent from 2000 to 2004, but then fell back again in 2005; it then worsened again by 2009 to a level worse than in 2004. These figures show that the extent of marine pollution measured in this way is probably significantly related to changing levels of runoff from land, since it is the levels of nutrients that are determinative (Wang et al., 2011).

Harmful algal blooms in Chinese coastal waters increased massively in number and extent since the 1990s, affecting areas up to 30,000 square kilometres (Wang et al., 2011). Since 2006, the areas affected by “red tides” have decreased, now being less than 20,000 square kilometres. The areas affected by “green tides” have, however, increased since 2008 (China, 2012).



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 9. Water Quality in 2014 in Major Bays along the Coast of China. Source: China NMEMC, 2015.

9.4.5 Bohai Sea, Yellow Sea, and the NOWPAP region

Assessment of relative inputs of nutrients to the Yellow Sea from China and the Korean Peninsula is not possible because comparable data are lacking. The same applies to discharges into the parts of the NOWPAP region[8]. From the pattern of

[8] The NOWPAP (Northwest Pacific Action Plan) was established by China, Japan, the Republic of Korea and the Russian Federation in 1994 as an integral part of the Regional Seas Programme of the United Nations Environment Programme (UNEP). As stated in the Northwest Pacific Action Plan, it covers the "marine environment and coastal zones of the following States: [Democratic People's Republic of Korea]; Japan; People's Republic of China; Republic of Korea; and Russian Federation from about 121°E to 143°E longitude and from approximately 52°N to 33°N latitude, without prejudice to the sovereign right of any State".

harmful algal blooms, however, it is clear that real problems exist here. Harmful algal blooms have been observed along all the coasts, particularly concentrated in the Bohai Sea, on the south of the Korean Peninsula and on the north-west of the island of Kyushu (Japan). Harmful algal blooms off the Chinese coast are usually judged to be much larger than those off the Korean Peninsula and Japan. This may be due to the means of observation: China uses aircraft more than the Republic of Korea and Japan, which rely on ships. In Russian Federation waters, the blooms are confined to Peter the Great Bay, and appear to be the result of the size of the local urban population: no serious harm is attributed to them (NOWPAP, 2007). A UNDP-GEF Strategic Action Programme has committed China and the Republic of Korea to reduce nutrient discharges to the Yellow Sea by 10 per cent every 5 years up until 2020 (UNDP, 2011).

9.4.6 North-West Pacific (Kuroshio and Oyashio Currents)

Japan has a long history of sewage collection and treatment. The sewage from about 85 per cent of the population is treated: about 60 per cent by sewerage networks and about 25 per cent by small local plants. Nutrient removal during sewage treatment is, however, much less common (JSWA, 2014). On the eastern coasts of Japan, there are problems of high levels of nutrients, but these appear to be confined to the more enclosed waters near major conurbations, such as Tokyo Bay and Osaka Bay (Japan MOE, 2009).

9.4.7 South-East Pacific Ocean

As with hazardous substances, the information available on a consistent basis is relatively old. What it showed is that major conurbations lack effective sewage treatment works: the Tumaco estuary in Colombia, the Gulf of Guayaquil (especially the inner area, where oxygen levels were so low that fish were absent) in Ecuador, areas near Ferrol, Callao and Ilo-Ite in Peru, and the bays of San Vicente, Valparaiso and Concepción in Chile showed high levels of nutrients, and consequent eutrophication problems (CPPS, 2000). In spite of substantial programmes of investment in sewage collection and treatment (Peru has increased the proportion of the population served from 9 per cent to 37 per cent between 1985 to 2010), problems remain. Likewise, high levels of fertilizer use add to the problems.

Darwin was one of the first to record red tides (algal blooms) in this area, but they remained rare until the 1980s. Since then, they have become frequent (several a year) along the whole length of the coast from Colombia to Chile (ISP, 2010).

9.4.8 South-West Pacific

The east coast of Australia suffers from enhanced levels of nutrient runoff. These are particularly serious for the Great Barrier Reef. Compared to pre-European conditions (before 1850), modelled mean annual river loads to the Great Barrier Reef lagoon have increased 3.2 to 5.5-fold for total suspended solids, 2.0 to 5.7-fold for total nitrogen and 2.5 to 8.9-fold for total phosphorus. However, the effects vary widely depending on the level of agriculture in the catchment. Almost no change in loading for most pollutants has been observed in the rivers capable of affecting the northern Great Barrier Reef, but there have been much greater changes in rivers capable of affecting the central and southern Great Barrier Reef. Given the sensitivity of the corals of the Great Barrier Reef, the risk of adverse effects is high. Recent work suggests that a substantial part of the decline in hard coral is due to the high nutrient levels in the southern areas (Bell et al., 2014).

Further south, more than half the estuaries in New South Wales are subject to double the natural levels of sediment and nutrient inputs, and around one-third of these estuaries have been cleared of more than 50 per cent of their natural marine vegetation. These and other pressures are directly linked to the poor water quality found in a high proportion of New South Wales estuaries: only 11 per cent of the estuaries have been found to comply more than 90 per cent of the time with the guidelines for chlorophyll-a. Many of the estuaries are under pressure from excessive inputs of sediments and nutrients, and altered freshwater inputs and hydrological regimes (SE2011 Committee, 2011).

In New Zealand, significant eutrophication problems generally only occur in shallow estuaries and bays with restricted circulation. Guidelines for nutrient discharge have been adopted to deal with these problems (ESNZ, 2014). However, delivery of suspended sediment to the sea around New Zealand is 1.7 percent of the world total delivery, when the New Zealand land area is only 0.2% of the global land area (Hicks et al., 2011).

10. Inputs of Radioactive Substances

The waters, biota and sediments of the ocean all contain radioactivity. Some of this is entirely natural, representing the dispersion of naturally radioactive isotopes throughout the earth and the effects of cosmic radiation. Some, however, is the product of relatively recent human activities: the use of atomic bombs during World War II, the testing of further nuclear weapons, discharges and emissions from nuclear power plants and nuclear reprocessing plants, dumping of radioactive waste, accidents involving nuclear material and other less significant activities. Some human activities that concentrate naturally occurring radioactive material (NORM) have a longer history.

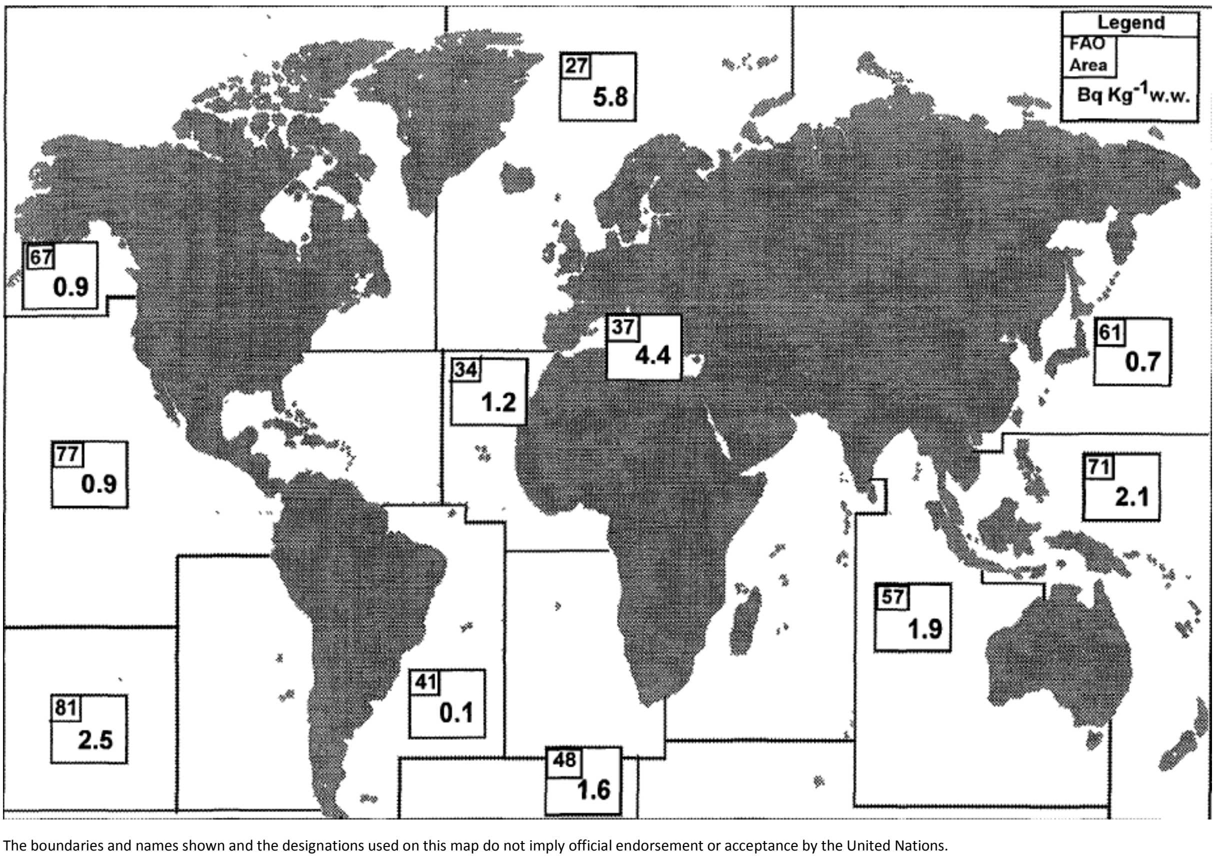
In considering radioactivity in the marine environment, it is essential to distinguish between:

(a) The occurrence of ionizing radiation, emitted through the decay of radionuclides, with the level of activity measured in becquerels (one becquerel being the activity of a quantity of radioactive material in which one nuclide decays every second); and

(b) The impact of such radiation on living organisms, where the energy deposited in the tissues of the organism (the absorbed dose) is measured in grays, and the sum of the effects of that dose on the different parts of the body (the effective dose) is measured, for humans, in sieverts. The biological effects of the absorbed dose vary according to the nature of the radiation (α-radiation can have a much more significant effect than β- or γ-radiation) and the part of the body affected. When the radioactive substance is incorporated into the body (for example, by being eaten), its effects integrated over a period of 50 years (70 years for children) are estimated through the committed effective dose, expressed in sieverts.

Naturally occurring radioactivity in the oceans

The natural background radioactivity in the ocean varies considerably. A study conducted under the auspices of the International Atomic Energy Agency (IAEA) in 1995 examined the variations between the FAO major fishing areas. This looked at the distribution of polonium-210 (^{210}Po), based on the view that, on a global scale, this isotope was radiologically the most important representative of naturally occurring radioactive material. The study concluded that insufficient evidence was then available to estimate the levels of polonium radioactivity in seawater in the different areas of the world. However, data for levels of polonium radioactivity in fish (shown in Figure 10), crustacea and molluscs for those areas for which data were available showed variations by factors of 58, 250 and 71, respectively, between the highest and lowest levels (MARDOS, 1995).



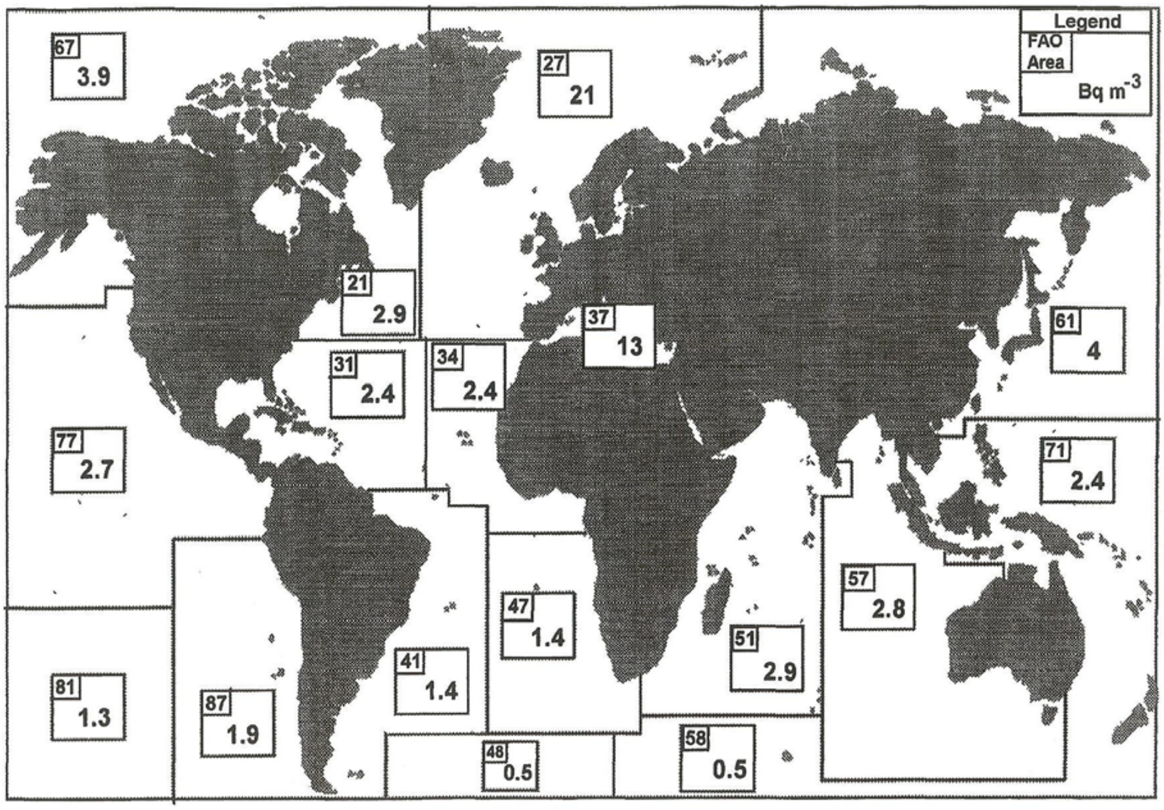
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 10. Concentrations of ^{210}Po in fish for FAO major fishing areas. Becquerels per kilogramme of wet weight. Source: IAEA, MARDOS, 1995.

10.1 Anthropogenic radioactivity in the oceans

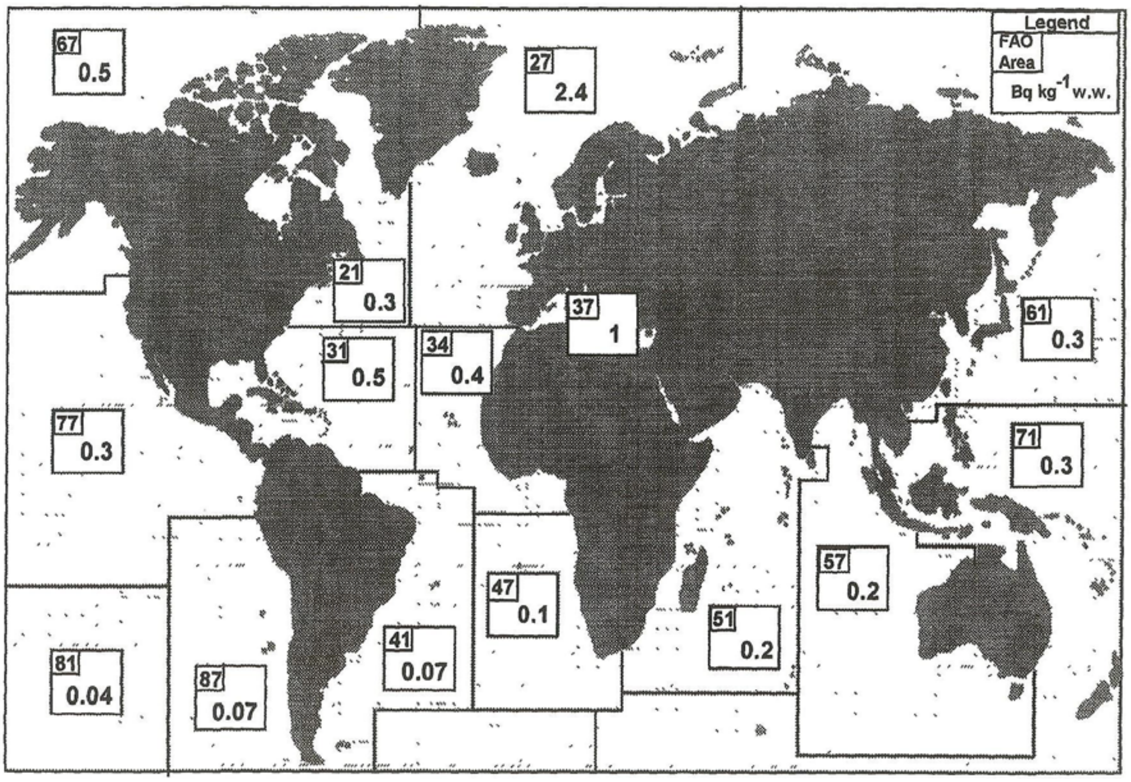
Anthropogenic releases of radionuclides into the ocean have had a measurable effect on the levels of radioactivity in the oceans and its distribution. The distribution in space and time can be quite complex, but is always related to four general processes: the type and location of the input, radioactive decay, biogeochemistry and oceanic processes, such as transport by ocean currents and sedimentation. The complex interaction of these processes over time means that all parts of the ocean are affected by anthropogenic releases of radionuclides, but that the distribution is quite varied. The 1995 IAEA study, using caesium-137 (^{137}Cs) as typical of anthropogenic radionuclides, estimated that radioactivity levels of ^{137}Cs in seawater and fish vary by factors of around 40-60 between the Southern Ocean (the lowest) and the North-East Atlantic (the highest) (MARDOS, 1995). Although the ocean contains most of the anthropogenic radionuclides released into the environment, the radiological impact of this contamination is low. Radiation doses from naturally occurring radionuclides in the marine environment (for example, ^{210}Po), are on average two orders of magnitude higher (WOMARS, 2005).

Becquerels per cubic metre



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 11. Concentrations of ^{137}Cs in seawater for FAO major fishing areas. Source: MARDOS, 1995.



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 12. Concentrations of ^{137}Cs in fish for FAO major fishing areas. Becquerels per kilogramme of net weight. Source: MARDOS, 1995.

10.1.1 Testing of nuclear weapons

Much of the anthropogenic radioactivity in the ocean derives from global fall-out from the atmospheric testing of nuclear weapons between 1945 and 1963. Most of this global fall-out resulted from the input of radioactive material from the explosions into the stratosphere. There was also additional local fall-out from material which did not reach the stratosphere. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) estimates that this global fall-out totalled around 2,500 million terabecquerels (TBq) (UNSCEAR, 2008). Using ^{90}Sr and ^{137}Cs as indicators, an IAEA study estimated that about 64 per cent of this fell on the oceans, of which 1 per cent fell on the Arctic Ocean, 26 per cent on the North Atlantic Ocean, 7 per cent on the South Atlantic Ocean, 14 per cent on the Indian Ocean, 35 per cent on the North Pacific Ocean and 17 per cent on the South Pacific Ocean. The IAEA study further estimated that the inventory of radioactivity from this source in the oceans had decreased (through natural decay) by 2000 to about 13,850,000 TBq. Much of this reduction was, of course, the result of the decay of short-lived isotopes (WOMARS, 2005). There have been no atmospheric tests of nuclear weapons since 1980, and so this major source of anthropogenic radioactivity appears to be purely historic.

10.1.2 Nuclear reprocessing

Overall, the second largest source of anthropogenic inputs of radioactive material into the ocean has been nuclear re-processing plants. In this sector, the major sources are the plants at Cap de la Hague (France: current capacity 1,700 tons/year of waste reprocessed) and Sellafield (United Kingdom: current capacity 2,100 tons/year). When the plants at these sites started work in the 1970s, relatively high levels of radioactive materials were discharged to the sea, reaching a peak in 1975 of 5,230 TBq of ^{137}Cs and 466 TBq of ^{90}Sr from Sellafield. Over the period 1970 – 1983, discharges from Cap de la Hague were much lower, representing about 2 per cent and 16 per cent respectively, of the levels of ^{137}Cs and ^{90}Sr discharges from Sellafield. In both cases, steps were taken to reduce discharge levels drastically, and new technology was developed and installed. The result was that aggregate annual discharges (other than tritium) from the two sites were reduced, by 2000, to around 98.2 TBq (0.2 TBq of α-emitting substances and 98 TBq of β-emitting substances other than tritium). Since then efforts at reductions have continued: by 2011, discharges were down to 18.2 TBq (0.1 TBq of α-emitting substances and 18.1 TBq of β-emitting substances other than tritium). This represents a reduction of 99.7 per cent from the peak of annual discharges (WOMARS, 2005; OSPAR, 2013; NEA, 2013). Although some States remain concerned at these discharges, the major impact is now only historic. It has been announced that one of the Sellafield plants (the Thermal Oxide Reprocessing Plant (THORP)) will close in 2018, when the currently programmed reprocessing has been completed, although this programme is currently reported to be behind schedule (NDA, 2014).

During the implementation of these reductions, some European States raised concerns about discharges of technetium-99 (^{99}Tc) from a new plant at Sellafield. Technetium has chemical properties close to those of manganese, which is naturally concentrated by many crustacea, especially lobsters. The ^{99}Tc discharges from the new plant at Sellafield were initially high: just over 180 TBq in 1994. This was substantially due to treating a backlog accumulated while the new plant was built, but ^{99}Tc discharges were still at around 40 TBq/year in 2003. In response to continued pressure from these European States, the United Kingdom has now implemented a chemical process to remove much of the ^{99}Tc from the discharge stream, and levels are now below 5TBq/year (OSPAR, 2010).

Other civilian reprocessing plants on much smaller scales were operational in Belgium, Germany and Italy, but have been closed since 1991 or earlier. China has a small nuclear reprocessing plant (capacity 50 tons/year) in operation in the inland province of Gansu. A larger plant (capacity 800 tons/year) is reported to be planned to start operation in the same province in 2017, and plans for a further plant exist. India has small reprocessing plants at coastal sites at Trombay (near Mumbai: capacity 60 tons/year), Tarapur (in Maharashtra: capacity 100 tons/year) and Kalpakkam (in Tamil Nadu: capacity 100 tons/year). A further plant (capacity 100 tons/year) was opened in 2011 at Tarapur, and further capacity is being built at Kalpakkam. Japan has a pilot reprocessing plant at Tokai on the coast north of Tokyo (capacity 40 tons/year) and is in the process of opening a large plant (capacity 800 tons/year) at Rokkasho (on the coast at the northern end of Honshu). No data on discharges from any of these plants seem to be available. The Russian Federation has operated the Mayak reprocessing plant (capacity 400 tons/year) near Ozyersk in the Ural Mountains since 1971. The nearby Lake Karachay has been used for the discharge of large quantities of radioactive waste. The IAEA 2005 study noted that this lake represents a potential source for future contamination of the Ob River system, and thus of the Arctic Ocean. New reprocessing facilities are also under construction at Zhelenogorsk, near the border with the Ukraine. Apart from the risk from Lake Karachay, there is no evidence to suggest that these other civilian reprocessing plants have led, or might lead, to significant contamination of the ocean (NEA, 2013; WNA, 2013; WOMARS, 2005).

10.1.3 Nuclear accidents

There have been two nuclear accidents that reached level 7 (the highest level) on the IAEA's International Nuclear and Radiological Event Scale: Chernobyl and Fukushima. These have resulted in substantial amounts of radioactive material reaching the ocean.

10.2 Chernobyl

On 26 April 1986, the Number Four reactor at the nuclear power plant at Chernobyl, Ukraine, went out of control during a test at low power, leading to an explosion and fire that demolished the reactor building and released large amounts of radioactive material into the atmosphere. Around 100,000 TBq of ^{137}Cs were released to the atmosphere. Although most of this activity was deposited on land, a significant part went to the sea, particularly the Baltic Sea. The total input of ^{137}Cs from Chernobyl to the Baltic Sea has been estimated at 4,700 TBq, including post-Chernobyl river discharges of ^{137}Cs to the Baltic Sea estimated at 300 TBq. Inputs from Chernobyl to the Black Sea have been estimated at 2,000-3000 TBq ^{137}Cs. The North Sea and the Mediterranean Sea also received inputs of radioactive material, and continue to do so through outflows from the Baltic Sea and Black Sea, respectively.

Because of the Chernobyl input, the Baltic Sea has the highest concentrations of ^{137}Cs of any sea region. Average concentrations of ^{137}Cs in fish from the Baltic Sea in 1990 were similar to those in the Irish Sea (which were affected by the Sellafield discharges), about 4 times higher than in the Black Sea, and about 30 times higher than in the Mediterranean Sea. However, radiation doses to humans in the Baltic Sea area from marine pathways (including those from ^{137}Cs in fish) during 1999-2006 have not exceeded an annual value of 0.02 mSv, and the dose for a person eating 90 kilogrammes a year of fish was estimated at 0.014 mSv over the period 2007 – 2010 – both well below the limit of 1 mSv per year for the general public set in the IAEA Basic Safety Standards. HELCOM assessments in 2009 and 2013 concluded that concentrations of radioactive substances in the Baltic Sea are not expected to cause harmful effects to wildlife in the foreseeable future (WOMARS, 2005; HELCOM, 2009; HELCOM, 2013). Likewise, a 2006 IAEA report concluded that radioactivity concentrations in marine fish resulting from the inputs from the Chernobyl disaster to the marine environment are not of concern (IAEA, 2006).

10.3 Fukushima

On 11 March 2011, a 9.0-magnitude earthquake occurred near Honshu, Japan, creating a devastating tsunami that left a trail of death and destruction in its wake. The earthquake and the subsequent tsunami, which flooded over 500 square kilometres of land, resulted in the loss of more than 20,000 lives and destroyed property, infrastructure and natural resources. They also led to the worst civil nuclear disaster since Chernobyl. Three of the six nuclear reactors at Fukushima Daiichi nuclear power station suffered severe core damage. This resulted in the release, over a prolonged period, of very large amounts of radioactive material into the environment. UNSCEAR concluded that the information available to it implied atmospheric releases of iodine-131 (^{131}I) and caesium-137 (^{137}Cs) in the ranges of 100,000-500,000 TBq and 6,000-20,000 TBq, respectively. (^{131}I and ^{137}Cs are two of the most significant radionuclides from the point of view of exposures of people and the environment). Winds transported a large portion of the atmospheric releases onto the Pacific Ocean. In addition, liquids containing radioactivity were discharged directly into the surrounding sea. The direct discharges amounted to around 10 per cent (for ^{131}I) and 50 per cent (for ^{137}Cs) of the corresponding atmospheric discharges. Low-level releases into the ocean were still ongoing in May 2013. The estimated releases are about 10 per cent (^{131}I) and 20 per cent (^{137}Cs) of the corresponding estimated atmospheric releases from the Chernobyl accident (UNSCEAR, 2013), but because of the sea-side site and the effects of the winds, the Fukushima event was the largest-ever accidental release of radioactive material to the ocean, being slightly more than the amount reaching the sea from the intrinsically much larger Chernobyl event (Japan, 2011; Pacchioli, 2013).

UNSCEAR further concluded that exposures of marine biota to radioactivity following the accident were, in general, too low for acute effects to be observed, though there may have been some exceptions because of local variability. Effects on biota in the marine environment would have been confined to areas close to where the highly radioactive water was released into the ocean (UNSCEAR, 2013).

Within a few weeks of the disaster, traces of ^{134}Cs were found over 1,900 km across the Pacific from Fukushima. By August 2011, bluefin tuna caught off California were found to contain ^{134}Cs which could only have come from Fukushima. ^{134}Cs has a half-life of only two years, and so material from pre-Fukushima sources (such as weapons testing) would have decayed long before. Further sampling suggested that the strong Kurushio current acted as a barrier preventing significant amounts of radioactive material moving south in the Pacific, and confining it to around the latitude of Fukushima (Pacchioli, 2013; Fisher et al., 2013).

In December 2013, the IAEA confirmed that a comprehensive Sea Area Monitoring Plan had been established, noting that radionuclide concentrations remain within the WHO guidelines for drinking water and that the public is safe. The IAEA assessment also addressed monitoring of food products, adding that the joint FAO/IAEA Division concluded that measures taken to monitor and rapidly respond to any issues regarding radionuclide contamination in the food system are appropriate and that the public food supply (including food from the sea) is safe (IAEA, 2013a; IAEA, 2014).

10.4 Other nuclear accidents

The 2005 IAEA study reviewed the full range of accidents involving radioactive material resulting in inputs to the ocean, but did not consider that the amounts were significant, beyond noting that the six sunken nuclear submarines which remain in the ocean with their reactors may be considered as potential sources of radioactive contamination of the ocean, and that nuclear-powered satellites burning up in the atmosphere on re-entry can affect radioactivity in the ocean (a 1964 incident over the southern hemisphere resulted in a measurable increase in the ratio between ^{238}Pu and ^{239,240}Pu between the northern and southern hemispheres (WOMARS, 2005).

10.4.1 Nuclear power plants

There were 434 commercial nuclear power reactors in 30 countries in operation at the end of 2013. The plants containing them have a total capacity of over 370,000 megawatts (MW). A little over 300,000 MW of this capacity is in OECD countries. About 72 more reactors are under construction. These plants produce over 11 per cent of the world's electricity: from nearly 75 per cent of the national supply in France to 1.5 per cent in the Islamic Republic of Iran (see Table 5). Other States which do not have nuclear power plants, such as Denmark and Italy, import substantial amounts of their electricity from neighbouring States which rely substantially on nuclear power (IAEA, 2013b). Electricity generated from nuclear power is therefore a significant source of energy.

Table 5. Proportion of electricity generated from nuclear power 2013.

STATE	PER CENT OF ELECTRICITY FROM NUCLEAR POWER	STATE	PER CENT OF ELECTRICITY FROM NUCLEAR POWER	STATE	PER CENT OF ELECTRICITY FROM NUCLEAR POWER
France	73.3	Bulgaria	30.7	South Africa	5.7
Belgium	52.1	Armenia	29.2	Mexico	4.6
Slovakia	51.7	Korea, Republic of	27.6	Argentina	4.4
Hungary	50.7	United States of America	19.4	Pakistan	4.4
Ukraine	43.6	United Kingdom	18.3	India	3.5
Sweden	42.7	Russia	17.5	Brazil	2.8
Switzerland	36.4	Romania	19.8	Netherlands	2.8
Czech Republic	35.9	Spain	19.7	China	2.1
Slovenia	33.6	Canada	16.0	Japan	1.7
Finland	33.3	Germany	15.4	Iran, Islamic Republic of	1.5

Source: IAEA PRIS Database, IAEA, 2013b.

Emissions and discharges are inevitable from the operation of these plants. For the purposes of the World Ocean Assessment, the crucial question is the extent of the impact of these emissions and discharges on the marine environment. The 2005 IAEA survey of sources of anthropogenic inputs of radioactive materials to the ocean commented that routine discharges from nuclear power plants contribute orders of magnitude less to the radioactive contamination of the world ocean than nuclear-weapons testing, nuclear reprocessing plants and nuclear accidents (WOMARS, 2005). The supporting material for the 2008 UNSCEAR report to the United Nations General Assembly gives a figure of approximately 1.3 TBq as the worldwide aggregate level of radioactivity from radionuclides other than tritium released from nuclear power plants in liquid effluents in 2002 (UNSCEAR, 2008). Data from some plants is not included but, as can be seen from comparison with the figures quoted above for other sources, this is consistent with the WOMARS conclusion. The 2008 UNSCEAR report further comments that radiation doses from nuclear power reactors decrease over time because of lower discharge levels. This is consistent with the observations recorded by the OSPAR Commission, which noted a statistically significant reduction of 38 per cent in total β-activity (other than tritium) from nuclear industries discharging into the North-East Atlantic (OSPAR, 2010). At the same time, aggregate discharges from nuclear power plants are likely to increase somewhat as the nuclear power stations under construction and planned come on stream.

Discharges of tritium are, however, rather different. The production of tritium by nuclear power plants is normally related to the level of electricity generated. No accepted abatement technology exists, and the amount of radioactivity in discharges can be many times that from other radionuclides. However, tritium is a natural product produced by cosmic rays. This source accounts for a significant amount of the radionuclide found in the sea. It also has a very low dose coefficient and therefore exhibits a very low radiotoxicity to humans and inherently low radiotoxicity to biota (OSPAR, 2007).

10.4.2 Human activities concentrating naturally occurring radioactive material (NORM)

A wide range of materials used in an even wider range of human activities contain natural radioactivity. The effects of the human activities can be to concentrate this naturally occurring radioactive material (NORM) from these materials, usually in the form of waste. Recent studies by the OSPAR Commission (summarized in OSPAR, 2010) conclude that the major source of NORM reaching the North-East Atlantic is the offshore oil and gas industry, where produced water (water coming from the reservoir with the oil and gas) and the scale that it deposits in pipelines (which has to be cleared periodically) contains low levels of radionuclides (mainly ^{210}Pb, ^{210}Po, and $^{226/228}$Ra). Although the proportion of total-α activity is higher than for discharges from the nuclear industries, the overall concentrations are not so far thought to be significant, although work to assess the levels is continuing. Apart from phosphate rock processing (see below), other anthropogenic sources of NORM in the marine environment are not thought to be significant.

One form of NORM reaching the marine environment that has been thought to be significant in some States is the ^{210}Po found in phosphogypsum, a by-product of the treatment of rock containing phosphate to produce phosphate fertilizers. In many cases, this phosphogypsum has been discharged directly into the sea as slurry. At Workington, England, in the area affected by the Whitehaven phosphate-processing plant releases, it was found that molluscs were concentrating this ^{210}Po to an extent that those who consumed substantial quantities of the molluscs might be ingesting ^{210}Po at potentially dangerous levels. The closure of the plant in 1992 resolved the problem. Similar problems were also found at a plant at Rotterdam in the Netherlands, which was also closed. For these and other reasons, this method of disposing of phosphogypsum has been phased out in most countries. It continues in Lebanon, Morocco (where it is under review) and South Africa (IAEA, 2013c).

10.5 Impact of radioactivity in the marine environment

Two issues need to be differentiated: the impact of radioactivity from the marine environment on humans, and the impact of such radioactivity on marine biota.

As far as concerns the radiation impact on humans through food from the marine environment, the IAEA MARDOS study in 1995 reported on the exposure of humans to ^{137}Cs and ^{210}Po, as the anthropogenic and natural radionuclides, respectively, of most radiological significance. This study concluded that, worldwide, the mean individual committed effective doses in 1990 were:

Table 6. Estimated mean individual committed effective doses in 1990 from ^{137}Cs and ^{210}Po

Radionuclide	Food source	Mean individual effective dose commitment worldwide (microsieverts)	Uncertainty factor as a result of limited data
^{137}Cs (anthropogenic)	Fish	0.03 µSv	0.5
^{137}Cs (anthropogenic)	Shellfish	0.002 µSv	0.5
^{210}Po (natural)	Fish	1.9 - 2.3 µSv	5
^{210}Po (natural)	Shellfish	2.8 – 7.2 µSv	5

Source, MARDOS, 1995

In another way of considering the data, the study identified the critical group of humans (the group most at risk) as those eating seafood from the North-East Atlantic, the FAO major fishing area with the highest levels of radioactivity. Taking as the definition of the critical group those consuming 100 kg of fish and 10 kg of shellfish per year (a daily consumption of about 300 g (about 10½ oz) of seafood), the total individual committed effective doses were estimated for 1990 at 3.1 µSv from ^{137}Cs and 160 µSv from ^{210}Po. There is no reason to consider that current levels would be significantly higher. All these figures must be considered in relation to the

IAEA's recommended annual limit for exposure of the general public to radiation of 1mSv (1,000 µSv).

For a long time, the International Commission on Radiation Protection (ICRP – the international body of experts that agrees standards of radiation protection) considered that the precautions necessary to protect humans will be adequate to protect other species: "The Commission believes that...if man is adequately protected, then other living things are also likely to be sufficiently protected" (ICRP, 1977). In the 1990s, this approach was questioned, particularly for habitats where humans do not go – which covers much of the marine environment. It was not suggested that there were any obvious cases where the approach was failing to protect non-human species, but rather that it was desirable to adopt an approach which would explicitly demonstrate the proper protection of the whole environment. The ICRP debated this extensively from 2000 and in 2005 set up a new standing committee to consider the radiological protection of the environment. This debate resulted in the inclusion of an approach for developing a framework to demonstrate radiological protection of the environment, as part of the general 2007 revision of the ICRP recommendations (ICRP, 2007). The ICRP considered that this approach needed to be based on a sound scientific system similar to that developed for human protection, and that this could best be achieved by the creation of a set of Reference Animals and Plants. Descriptions of 12 "reference animals and plants" have been developed, of which three – a flatfish, a crab and a seaweed – are relevant to the marine environment. These are generic biological descriptions of the types of animal and plant, accompanied by consideration of their vulnerability to radiation and the relationship between environmental levels of radionuclides and the corresponding levels in such animals and plants. Most recently, in 2014, the ICRP has published guidance on the application of their recommendations to different exposure situations with respect to the animals and plants living in different types of natural environments. Central to this approach is the "Derived Consideration Reference Level" (DCRL): a band of dose rates within which there is some chance of a deleterious effect from ionizing radiation occurring to individuals of that type of Reference Animal or Plant. The recommended DCRLs are shown in Figure 13 (ICRP, 2009; ICRP, 2014). This work is being taken forward through the IAEA International Plan of Activities on the Radiation Protection of the Environment.

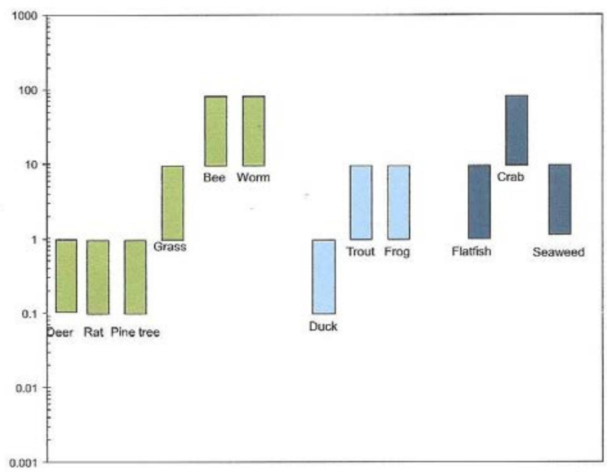


Figure 13. Derived Consideration Reference Levels for Reference Animals and Plants. In milligrays (mGy)/day. Source: IPRC, 2014.

11. Significant environmental, economic and social aspects of land-based Inputs and related information and capacity-building gaps

The world needs to feed, clothe, house and keep happy its 7¼ billion people. The agricultural and industrial developments of the past two centuries have substantially enabled this to be done and, to a significant extent, have assisted in improving human well-being. But these achievements have been obtained at a price: these agricultural and industrial developments have seriously degraded important parts of the planet, including much of the marine environment. Land-based inputs to the ocean have contributed substantially to this degradation of the marine environment.

The GPA highlighted the need for action to deal with sewage. Although much has been done to implement national plans adopted under the GPA, particularly in South America, this chapter shows that lack of sewage systems and waste-water treatment plants is still a major threat to the ocean. This is particularly the case in respect of very large urban settlements. The lack of proper management of waste-water and human wastes leads to excessive inputs of both nutrients and hazardous substances, which damage the marine environment. It also causes problems for human health, both directly and through bacteriological contamination of food from the sea.

From the point of view of industrial development, many of the earlier industrial processes brought with them serious environmental damage, especially when concentrations of industry led to intense levels of waste inputs to the sea, beyond its carrying capacity. New technologies and processes have largely been developed which have the ability to avoid these problems, but there can be gaps in the capacity to apply these newer processes, often because of the costs involved.

This is particularly significant because of the major transfer in the growth of industrial production demonstrated in this chapter. In the past, industrial production has been dominated by the countries around the North Atlantic basin and its adjacent seas, together with Japan. Over the past 15 years, the rapid growth of industries along the rest of the western Pacific Rim and around the Indian Ocean has changed this. Rapidly growing proportions of the world's industrial production – and the associated waste discharges – are focused on the South Atlantic, the Indian Ocean and the western Pacific.

The survey in this chapter shows that some major information gaps need to be filled before this process of industrial growth can be managed in a way that can avoid reproducing, in the new areas of growth, the many problems that have been discovered in the areas that have been industrialized longer. For long stretches of the coastal zones, information is lacking on what is happening with heavy metals and other hazardous substances. Information is also lacking on the extent to which developing industries are able to apply the newer, cleaner technologies. Moreover, information is very scarce on how problems in the coastal zones are affecting the open ocean.

The agricultural revolution of the last part of the 20th century, which has largely enabled the world to feed its rapidly growing population, has also brought with it problems for the oceans, in the form of enhanced runoff of both agricultural nutrients and pesticides, as well as the airborne and waterborne inputs of nutrients from wastes from agricultural stock. In the case of fertilizers, there is a rapid growth in their use in parts of the world where only limited use has occurred in the past. This has the potential to lead to increased nutrient runoff to the ocean, if the increased use of fertilizers is not managed well. There are therefore problems in educating farmers, promoting good husbandry that causes less nutrient runoff and monitoring what is happening to agricultural runoff alongside sewage discharges. In the case of pesticides, the issues are analogous to those of industrial development. Newer pesticides are less polluting than older ones, but gaps remain in the capacity to ensure that these less-polluting pesticides are used, in terms of educating farmers, enabling them to afford the newer pesticides, supervising the distribution systems, and monitoring what is happening in the oceans.

The growth of dead zones, resulting from excessive nutrient runoff and the consequent eutrophication problems, is serious in terms of all three of environment, economics and society. The dead zones drive fish away and kill the benthic animals. Where the dead zone is seasonal, such regeneration as happens is usually at a lower trophic level, and the ecosystems are therefore degraded. This affects the maritime economy seriously, both for fishers and (where tourism has some dependence on the attractiveness of the ecosystem (for example, where there are coral reefs)) for the tourist industry. Social consequences are then easy to see, both through the direct economic effects on the fishing and tourist industries and in depriving the local human populations of the benefits of an attractive environment.

In respect of heavy metals and hazardous substances, frameworks have emerged at the international level for addressing some of these problems. In particular, the Stockholm Convention on Persistent Organic Pollutants and the Minamata Convention on Mercury provide agreed international frameworks for the States that are party to them to address the issues that they cover. Implementing them, however, will require many capacities and, as the organizations involved with these

Conventions have noted, there are important gaps in those capacities around the world.

In the case of radioactive discharges into the ocean, the survey shows that, in the past, there have been human activities that have given rise to concern, but that reactions to these concerns have largely removed the underlying problems, although there is a continuing need to monitor what is happening to radioactivity in the ocean. What remains is the concern voiced in the GPA that public reaction to concerns about marine radioactivity could result in rejection of fish as a food source, with consequent harm to countries that have a large fisheries sector and damage to the world's ability to use the important food resources provided by the marine environment.

Underlying all these issues is the major information gap in the information needed to see what is happening around the world to the ocean as a result of land-based inputs. This chapter has noted a range of differing systems for assessing the state of the ocean in respect of both hazardous substances and eutrophication. These systems usually differ for good reasons: conditions vary widely around the world. There is a lack, however, of methods to compare explicitly the information that each assessment system produces. This does not imply a need for a single global system of monitoring: as has been said, good reasons for the differences often exist. But an important gap in information results from the lack of any means of comparing the answers given by the different assessment systems. Comparison between monitoring systems also presupposes good quality-assurance of monitoring data.

An even more important gap in information is the absence of any form of regular, systematic assessment of the impact of land-based inputs in many parts of the world. In some parts of the world, such as the Caribbean, many one-off, independent examinations of several aspects of the marine environment have been undertaken, but they are not in forms which enable them to be assembled into a wider, continuous assessment. Given the potential significance of transboundary effects from land-based inputs, this is a very serious information gap. In at least some parts of the world where this is the case, universities and marine research institutes have the capacity to carry out the monitoring and analysis that is needed: what is lacking is more the capacity to organize these existing capacities to fill the wider information gap.

In summary, therefore, important changes are under way in the location around the world of industrial activity and agriculture, which have the potential to cause serious problems if past errors are reproduced. Worrying gaps exist in the capacities needed: to provide sewerage systems and waste-water treatment plants, to implement international conventions regulating which substances can be put into the sea from the land, and to monitor what is happening in the marine environment as a result. Finally, overall, major gaps remain in knowledge about land-based inputs and what knowledge about them is available in different parts of the world.

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