POLLUTION OF THE HYDROSPHERE AND QUALITY CONTROL IN NATURAL WATERS

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Summary

The term hydrospheric pollution refers not only to water quality but also to biodiversity and habitats. Pollution can be classified as either reversible or irreversible, based on duration. Reversible pollution lasts for less than one hundred years. Examples include the acidification of lakes and rivers, the introduction of heated cooling water from power plants, harmful algal blooms, oil pollution, the introduction of metals, and excessive aquaculture. These forms of pollution cause damage to ecosystems, but the

systems generally recover within one hundred years of eliminating the pollutants. Examples of irreversible pollution include the presence of environmental endocrine disrupters and radioactive pollution, the introduction of non-indigenous species, the destruction of habitats through construction and reclamation, and global warming. Irreversible pollution must be avoided at all costs. Monitoring is essential, not only to evaluate pollution levels in the hydrosphere and provide data for studies of how to ameliorate hydrospheric pollution, but also to forecast future environmental conditions. Since pollution knows no boundaries, monitoring must be within an international framework. Most pollution is caused by human activity on land. Water and ecosystem quality in the hydrosphere depends on comprehensive management. This management must be undertaken throughout the entire watercourse, from the initial stages of precipitation, through mountains, rivers and lakes, to the final destination of the sea. To control pollution in the hydrosphere, developments must continue in three key areas: waste reduction; waste recycling, and the development of cleaning technologies. Changes in consumer behavior could result in massive reductions of waste. Reduced consumption and industrial development in process technology would be of significant benefit. By the year 2000, 75% of the world's population were living within 60 km of the coast. Integrated coastal management and international cooperation have become essential as the increase in population has led to the degradation of coastal ecosystems through factors such as increased urban waste, construction and land reclamation. This trend will continue unless preventive measures are taken. The tendency for populations to settle in coastal areas must be limited to a level that does not exceed the carrying capacity of the natural ecosystem. It is also necessary that cleaning technology be transferred to developing countries.

1. Introduction

Early in the twentieth century, hydrospheric capacity was thought to be unlimited. This assumption was based on the fact that the oceans make up a full two thirds of the Earth's surface. During the twentieth century, agriculture, fisheries, forestry, mining and industry have expanded rapidly. This expansion has been accompanied by increasing pollution. The world population is expected to increase from 5.9 billion (in 1998) to 8 billion, by 2025. It has been estimated that 75% of the world's population were living within 60 km of the coast in 2000, and that this percentage is increasing. This trend has both direct and indirect impacts on hydrospheric environments, and by the end of the twentieth century, their combined effect began to exceed the ability of the hydrosphere to rebound. In the next century, we must reverse these effects and attain co-existence within the hydrosphere. This article discusses hydrospheric pollution and proposes methods for maintaining quality control in natural waters.

The term "pollution" is generally understood to refer to the environmental damage caused by waste that is discharged into the hydrosphere. It is also used to refer to the occurrence of waste in the hydrosphere or to the presence of waste itself. The United Nations Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP), and the International Council for the Exploration of the Sea (ICES), have recommended the use of the following terms. The term "inputs" is to be used for waste in the sea (hydrosphere), the term "contamination" is to be used for the occurrence of waste in the sea, and the term "pollution" is to be used for the damaging effects of this waste.

Classifying pollution is helpful for understanding its degree of impact. Meinesz has recommended four categories, based on the duration of impact:

- Short-term pollution disappears within about ten years after the cause of the pollution has been eliminated.
- Middle-term pollution is caused, in the main, by non-biodegradable chemicals that are active on fauna and flora. This type of pollution generally has a duration of several decades. Here, non-biodegradable chemicals are classified as those causing irreversible pollution due to their persistence in the hydrosphere.
- Long-term pollution causes ecosystem destruction and usually requires reconstruction that takes at least one hundred years.
- "Point-of-no-return" pollution is irreversible and results in the definitive destruction of a species or ecosystem. Any associated reconstruction period is longer than several centuries.

If the cause of the pollution is not eliminated, short-term pollution can become middle term. The time period used in the above definition is based on the period once contamination ends. Short, medium and long-term pollution are all reversible (non-conservative), while point-of-no-return pollution is irreversible (conservative). Irreversible pollution occurs when pollutants that do not decompose for at least several hundred years accumulate. Meinesz has claimed that reclamation is actually irreversible pollution because of the impossibility of reinstating reclaimed coast to its original condition, and the fact that the reclaimed area exists quasi-perpetually. Irreversible pollution is incompatible with sustainable development.

By contrast, the term reversible pollution implies that pollutants can be decomposed or diluted by natural forces. An oil spill offers a good example of reversible pollution, as oil disappears within ten or twenty years. Appropriate policies can effectively control this kind of pollution by removing the source of inputs or by improving the way discharged water must be treated.

It is important to keep in mind that hydrospheric inputs can easily traverse national boundaries and cross seas and oceans. Polychlorinated biphenyls (PCBs) and other chemicals diffuse in air and can enter water through fallout; thus, air-diffused pollutants can also traverse national boundaries and affect other countries. Pollution and water quality must be controlled not only through national standards but also through international cooperation.

To prevent pollution, world hydrospheric conditions must be well understood, making international monitoring imperative.

2. Pollution Occurring in the Hydrosphere

This section describes various types of pollution and classifies each as reversible or irreversible. The classifications used here are not definitive, but serve to improve our understanding of the characteristics of pollution and its impact.

2.1 Reversible Pollution

2.1.1 Acid Precipitation and UV-B Radiation

Acid precipitation is produced by SO_4^{2-} or NO^{3-} that is released into the atmosphere as a result of industrial processes. In lakes with poor chemical and/or biological buffering capacity, continuous acid-water influx acidifies the lake water. This acid lake water affects both flora and fauna. Research conducted on Swedish lakes has shown that salmonid and cyprinid fish disappear from lakes with a pH of less than 5.5. Studies on Norwegian lakes have revealed that the lethal low pH for Gammaridae (amphipods, which are an important food source for salmonid fishes) is 6.0. In acidified lakes, the presence of algae and submerged vascular plants tends to decrease while the presence of Sphagnum tends to increase. Because *Sphagnum* is found in lakes with pH levels between 4 and 5, it can be used as a reliable bioindicator.

UV-B radiation is increasing as a consequence of ozone depletion caused by CH_4 and Freon. Some studies have indicated that this may reduce the productivity of phytoplankton in surface waters (including open oceans). The possible impact on marine organisms is, as yet, unclear; more research is needed to evaluate these effects.

2.1.2 Harmful Algal Blooms

Harmful algal blooms (HABs) can be defined as events in which the concentration of one or several algal blooms reaches levels that can cause harm to other sea organisms. There is no general rule by which a level of cell concentration at which harm occurs may be identified; such concentration levels in HABs are species specific. One type of HAB, which causes death to fish as a result of diatoms, is globally distributed (see Figure 1).

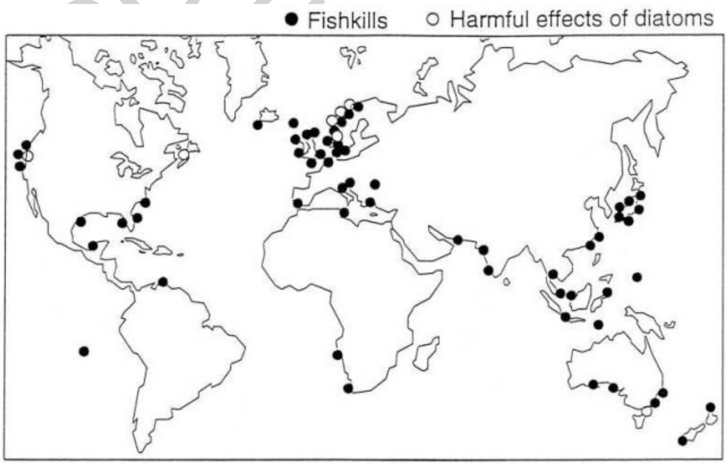

Figure 1. Global distribution of wild and cultured fish kills and harmful effects of diatoms.

Anderson classified HABs into one of four categories, according to their effects:

- Blooms of species that produce generally harmless water discoloration. In this type of HAB, the recreational value of the bloom area decreases, due to low visibility. Under exceptional weather conditions, in sheltered bays, the bloom can grow so dense that it causes escape reactions and indiscriminate fish kills, due to choking. The gill rakers are clogged with phytoplankton and oxygen is depleted. Benthic invertebrates are also killed as a result of oxygen depletion. This type of bloom is referred to as a red tide. Red tides are prompted by the eutrophication that brings nitrogen and phosphate to phytoplankton. Examples of species causing this type of bloom are dinoflagellates (*Prorocentrum micans*), diatoms (*Skeletonema costatum*), cyanobacteria (*Trichodesmium erythraeum*), other flagellates (*Eutreptiella* spp.) and ciliates (*Mesodinium rubrum*).

- Blooms of species that produce potent toxins, which accumulate in food chains and cause a variety of gastrointestinal and neurological illnesses in humans and other higher animals on consumption. They are classified into six groups, according to the symptoms produced: (a) paralytic shellfish poisoning (PSP), caused by organisms such as *Alexandrium* spp. and *Gymnodinium catenatum*; (b) diarrheic shellfish poisoning (DSP), caused by organisms such as *Dinophysis* spp.; (c) amnesic shellfish poisoning (ASP), caused by organisms such as *Pseudonitzschia* spp.; (d) ciguatera fish poisoning (CFP), caused by organisms such as *Gambierdiscus toxicus*; (e) neurotoxic shellfish poisoning (NSP), caused by organisms such as *Gymnodinum breve*; and (f) cyanobacteria toxin poisoning (CTP), caused by *Anabaena flos-aquae*, etc.
- Blooms of species that, in most cases, are non-toxic to humans but harmful to fish and invertebrates (especially in intensive aquaculture systems) by, for example, intoxication, or by damage or clogging of the gills, or by other means. Species of this kind include *Heterosigma akasiwo*.
- Blooms of species that produce toxins that are toxic to humans, which are transported by air in aerosols from the bloom area to the coast. The species are *Gymnodinium breve* and *Pfiesteria piscimortuis*. Recent research has discovered a further type (4) species, a dinoflagellate, *Pfiesteria pisicida*. This species is distributed in estuaries along the east coast of the US. A few dinoflagellate *Pfiesteria*-like species are distributed along the south coast of the US. These organisms have been associated with fish lesions and kills in coastal waters. Some researchers have speculated that *Pfiesteria* becomes toxic only in the presence of fish; particularly schooling fish like Atlantic menhaden, and is triggered by their secretions or excrement. *Pfiesteria* cells can change form and emit a strong toxin that stuns fish and makes them lethargic. Other toxins are believed to break down skin tissue in fish, opening bleeding sores or lesions. Evidence suggests that exposure to waters where toxic forms of *Pfiesteria* are active may cause memory loss, confusion, and a variety of other symptoms, including respiratory, skin, and gastro-intestinal problems. Some have postulated that the eutrophication of rivers and estuaries by nutrients from swineries along rivers can prompt outbreaks of *Pfiesteria*.

2.1.3 Heat

Nuclear-, oil- and coal-fired power plants use huge amounts of water from rivers and coastal waters. This water is heated in cooling processes. Worldwide, about 20 million m^3/day of cooling water, 12°C above the ambient sea temperature, is discharged in the generation of 1000 MW of electricity by oil- or coal-fired power plants. Nuclear power plants discharge water 15°C above ambient sea temperature. Small fish and plankton are entrained in the cooling water, and the water is treated with chlorine to discourage the settlement of organisms in the heat-exchange system. Since heat shock and chemical stress kill most of these organisms, biological damage is substantial.

The discharge of hot water causes thermal stress to organisms in natural habitats of the hydrosphere. This is especially true for benthic organisms such as seagrass, macro algae, and shellfish. In the Japan Sea, catches of migrating species such as yellow tail and flying fish have fallen as a result of changes in migration courses following hot-water discharge from nuclear power plants. In subtropical areas, electricity demand peaks in the summer, when the sea temperature is near its annual maximum. In this situation, when discharge occurs, water with temperatures as high as 30-35°C--a level lethal to many organisms--is the result.

2.1.4 Man-Made Debris

A substantial amount of man-made plastic debris floats in the sea or sinks to the seabed. Based on sighting surveys from ships, we know that this debris is composed mainly of polystyrene foam, polyvinyl and plastics. Since this type of debris does not decompose, quantities continue to grow. In the North Pacific, a sighting survey on floating debris (plastic products), conducted between 1987 and 1991, showed that the highest density of plastic products can be found near the Pacific coast off Middle America, and in the Caribbean Sea. Presumably these plastics originate from the coastal areas, which have large populations.

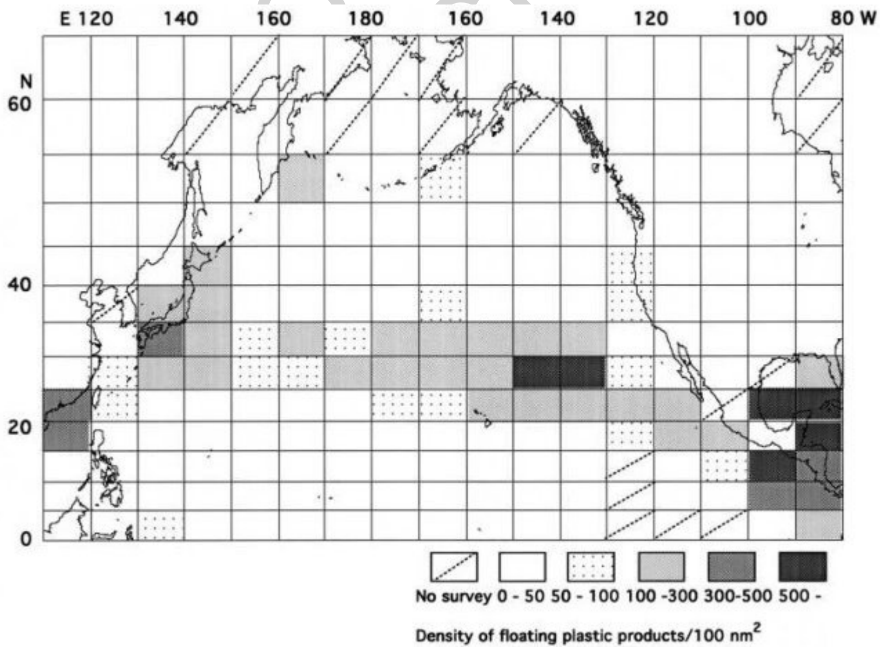

Figure 2. Distribution of floating plastic products
in the North Pacific from 1987 to 1991.

Areas that were next highest in plastic debris density were in the north of the South China Sea (which also has a large coastal population area), and northeast of Hawaii, where eddy currents trap debris. In addition, debris from the bottom is collected by trawl nets; researchers found that 70% of bottom trawls were fouled with debris in the eastern Mediterranean, 57% in Alaska, and over 40% in the Bering Sea.

Plastic pellets 3 to 4 mm in diameter, i.e., weathered fragments of larger plastic articles, are widespread throughout the oceans of the world. They are ingested by larval and adult fish, as well as by surface-feeding seabirds. It is uncertain whether these pellets are harmful. Larger pieces of plastic debris, however, are deadly to sea fauna. Plastic bags and sheeting are often consumed by sea turtles that confuse them with jellyfish. A substantial portion of large fish, and 59% of beached turtles, are found with plastic cups and other objects in their digestive tracts. Seal pups play with discarded plastic strapping bands (used to bind pallets on cargo ships) or fragments of fishing nets. After the plastic becomes lodged around the animal's neck or flipper, it tightens as the animal grows, with strangulation or fatal laceration being the ultimate result. Plastic fishing nets continue to "ghost fish" long after being lost or abandoned at sea, ensnaring and killing fish, birds, and any other marine animals. One nine-mile-long gill net, found floating off the coast of Alaska, was discovered to have caught 350 seabirds as well as hundreds of valuable salmon. Monofilament line also becomes ghost fishing gear near the coast.

2.1.5 Oil Pollution

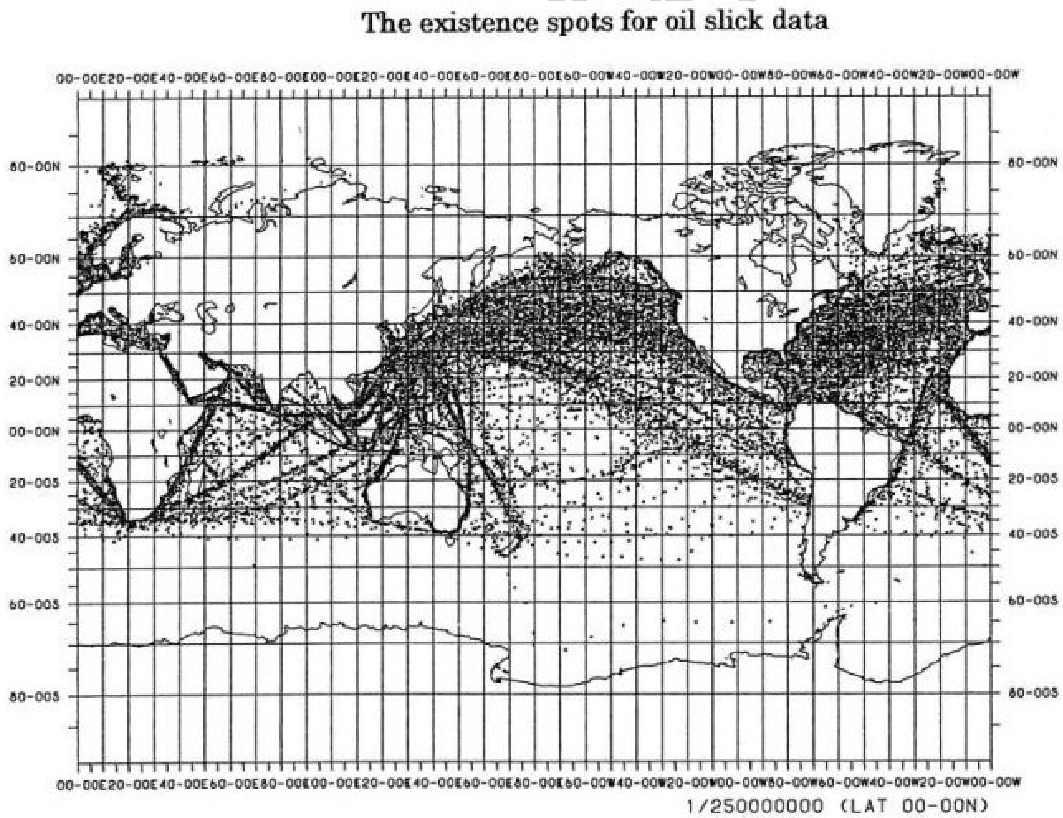

Figure 3. Distribution of oil slick data in oceans.

Oil spills attract public attention, as they offer dramatic scenes of endangered ecosystems. However, oil inputs to the sea are not simply the result of oil spill accidents; ordinary oil leaks are also to blame. Bilge and fuel oil, municipal and industrial waste, and atmospheric fallout are just as damaging as tanker operations and accidents. The dots in Figure 3 show areas of observed oil glitter on the sea surface. The pattern of these dots corresponds closely to modern shipping lanes. The oil is carried into the sea when ballast and bilge water are pumped overboard.

The impact of oil spills is not as great on rocky shores, as these areas have high-energy beaches. Wave action and water movement remove stranded oil quickly. This is not the case, however, on low-energy, sedimentary beaches. The effects of the Amoco Cadiz accident, for example, have lasted for decades. In the same way, stranded oil remains for extended periods of time in salt marshes, sea grass beds and among tropical mangroves in inter-tidal mud.

The effect of oil spills on seabirds is the most dramatic, and tends to be covered most widely by the media. The level of damage depends on whether the oil encounters individual seabirds or entire colonies. When the Amoco Cadiz spilled 223,000 tonnes of crude oil on the Brittany coast in March 1978, only 4,572 seabirds died. The Exxon Valdez spilled only 37,000 t of crude oil in Alaska in March 1989, but killed over 30,000 seabirds.

Oil pollution damages aqua-cultured fish and shellfish because they cannot escape. Wild adult fish, on the other hand, are not so gravely affected. Intertidal shellfish and crab populations can be devastated by oil pollution.

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Biographical Sketch

Teruhisa Komatsu graduated from the Department of Fisheries, Faculty of Agriculture, Kyoto University, Japan, and completed both Masters and Doctorate studies at the Graduate School of Agriculture (Fisheries Science), Kyoto University. He was then involved in research at the Laboratory of Fisheries' Physics at Kyoto University. From there he moved to the Ocean Research Institute as an assistant professor. He obtained a high level (haut niveau) French Government Scholarship, and resided at the Laboratory of Marine Littoral Environment at l'Université de Nice-Sophia Antipolis for 15 months. Currently he is an associate professor in the Division of Behavior, Ecology and Observation Systems at The University of Tokyo. His research has focused on marine organisms and their coastal and marine environment. His doctoral thesis discussed the interaction between the *Sargassum* (brown algae) forest and its marine environment. He studied the ecology of *Caulerpa taxifolia*, a tropical green alga introduced into the Mediterranean Sea, at the Laboratory of Marine Littoral Environment, at Université de Nice Sophia-Antipolis. Teruhisa's interests include marine pollution in relation to the sustainable development of fisheries, and his studies have now been extended to sampling and observation systems, especially remote sensing using acoustics and satellite imagery. He is a member of the Faculty Committee of the Graduate School of Agriculture and Bioscience, The University of Tokyo, and is also a member of several academic societies, including the Japanese Society of Oceanography, the Japanese Society of Fisheries Science, the Japanese Society of Fisheries Oceanography, and the Société Franco-Japonaise d'Océanographie. He is an executive committee member of Japan GLOBEC and the Japanese Society of Fisheries Oceanography.