Review Articles: Tankships in the Marine Environment

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Thomas Höfer*

Corresponding address: Dr. Thomas Höfer, Federal Institute for Health Protection of Consumers and Veterinary Medicine (BgVV), Postfach 330013, D-14191 Berlin, Germany

Part II: Environmental and Health Effects Resulting from Marine Bulk Liquid Transport

Abstract

There are a number of harmful effects that have been induced by emissions from large vessels carrying bulk liquids. These are reviewed.
A number of hazards are cargo-specific. Of special concern are liquids which after discharge or spillage float on the surface of the sea. Sea birds are regularly victims of discharged oil, most of which, however, is discharged from machinery spaces from all kinds of ships. Marine mammals have been contaminated or killed after tankship spills. Water soluble discharges may accumulate in fish and shellfish, thus tainting or contaminating seafood. Spills and discharges of toxic substances create direct hazards to human health.
There are also hazards which are not connected with the cargo. Tankships have large hulls which are covered with antifouling paint and consequently emit toxic chemicals. Empty sea-going tankships have to be ballasted with large quantities of water. By discharging the ballast water before loading, foreign material is introduced into that remote marine environment. Connected with this are hazards for the marine environment as well as for human health.

Keywords: Anti-fouling paints; ballast water; environmental effects, marine transport; health effects, marine transport; health hazards; discharges, spills; marine environment; marine pollution, discharges, spills; noxious substances; tainting of seafood; tankships; transport, marine

1 Introduction

Thousands of large sea-going tankships transport bulk liquids. This transportation undoubtedly is connected to environmental and health hazards. The traffic and the volumes of liquids discharged either accidentally or operationally including their general effects have been reported (see first part of the Report on "Tankships in the Marine Environment", ESPR 2/98, pp. 97-104). This article focuses on these harmful effects which are studied and connected to sea-going tankships. Most of these effects are not theoretical (hazards), they have already been proven (damage). However, this paper is neither intended to decide on the relevance of the effects for the whole marine ecosystem under the aim of a "sustainable development" nor to define the general environmental impact of the fleet. Many effects are not realized and hence not discussed here either because the funding of global marine research is relatively low or because detailed data on the operation of the fleet are not published. This review refers to dangers already known, some are experienced after spills, others are of a continous nature.

2 Effects On Sea-Birds

Many lipophilic substances are liable to produce a film on the surface of water. Several groups of products carried in large amounts in tankers can potentially cause this effect: all kinds of mineral oil and vegetable as well as animal oil (e.g. palm oil, fish oil). The feathers of swimming or diving birds rapidly absorb the floating film destroying the natural lipid coating. The structure of the plumage is of crucial importance in water repellency and insulation. Any disarrangement, e.g. the increase of contact angle induced by wax, affects the function (Bommele, 1991). Coating of fur or feathers results in major conductance resulting in a greater heat flow across the body surface and a loss of body heat, which must be compensated for by an increase in metabolism. As a result of energy depletion the animals die. It may be anticipated that animals suffer more in colder climates and under stormy conditions, resulting in a higher mortality than under mild conditions. The effects of external oiling may be exacerbated by the toxic effects of oil which is ingested as the thermally-stressed birds attempt to clean themselves.

*The views and conclusions expressed are those of the author only and do not reflect decisions, policies or views of any organization concerned. This review goes beyond what is the area of responsibility of the BgVV as a competent authority for health aspects of the transport of dangerous goods. The article has neither been subjected to BgVV review nor been approved as an official publication of this institute.

Depending on the environmental conditions and the population density, the number of birds contaminated and killed varies. After accidental discharges of large volumes, killed oiled birds are counted in many cases (→ *Table 1*). According to the data no direct correlation between the volume of oil discharged and the number of killed birds can be established.

Table 1: Number of killed Seabirds and Accidental Discharge Volumes of Mineral Oil (Examples)

Tons of Spilled Oil	Killed Birds	Name of Ship
90	1,100	Tank Duchess
150	3,000	Palva
1,200	3,700	Esso Bernica
2,700	7,000	Arizona St. & Oregan St.
6,500	>12,000	Arrow & Irving Whale
17,000	5,000	Seestern
38,000	<300,000	Exxon Valdez
86,000	<1,500	Braer
120,000	> 30,000	Torry Canyon
223,000	4,500	Amoco Cadiz

Penguins are very vulnerable to pollution with oily slicks. Four particularly serious incidents occurred off South Africa in the first half of 1968. The loss of crude oil by the ships Sivella (in February), Esso Essen (in April), Andron (in April) and World Glory (in June) killed a large part of the regional penguin population (BAKER, 1976). Some 4000 birds, mainly penguins, are also known to have been killed during the winter after the grounding of the Metulla in the Strait of Magellan (Chile) in 1974 (BAKER, 1976). Fortunately, the bulk of those local bird populations was elsewhere at the time of the spillages and the losses had no serious long-term effect on the population. However, it seems likely that only a fraction of the bird mortality was recorded in these areas off the South African and South American coasts (BOURNE, 1976).

Canada, in an official document to the IMO, declared that oiled bird mortality is affecting the long-term viability of some seabird populations. Canadian estimates of seabird mortalities in Newfoundland waters based on beached bird surveys suggest annual mortalities of between 20,000 and 100,000 birds from oil (IMO, 1998a). However, the majority of these were heavy fuel oils, many with additions of lubricating and hydraulic oils, which suggest that the contamination arises from oil machinery wastes from all kinds of vessels, not from tanker cargo space discharges.

Within one month (January 1994) about 3,000 oiled birds had been found along the coasts of the Irish Sea (EARL, 1994a). In February the same year, a total of 70,000 seabirds the vast majority non-oiled, had been washed ashore along the North Sea coasts of the British Isles (EARL, 1994b). Most of the estimates indicate that only 10 to 50% of the birds that die at sea ever wash up on beaches (BURGER, 1997). Published data for Western Europe indicate that the number of birds killed by oil is in tens of thousands (below one hundred thousand) while the number of birds dying naturally is in hundreds of thousands (DUNNET, 1982). Within the English Channel and the North Sea during the 1970s and 1980s, about 70% of all beached birds along the coasts of the United Kingdom (e.g. DUNNET, 1987), Belgium (e.g. KUYKEN, 1978), the Netherlands (e.g. CAMPHUYSEN, 1989), Germany (e.g. VAUK, 1989) and Denmark had been oil victims. A steady improvement during the 1980s resulted in about 30% oiled birds along the North Sea coasts (SKOV, 1991; AVERBECK, 1992a). French surveys in the late 1980s analyzed 37% birds oiled (RAEVEL, 1992). DUNNET (1987) concluded that British beach surveys suggest that chronic oil-induced mortality is at a relatively low level with no important impact on seabird populations. The real cause of death is not easily diagnosed within all of the surveys along the beaches. The decline in the number of oiled beached birds during the late 1980s and the 1990s may reflect the success of oil pollution control measures within the North Sea region and the free of charge oil disposal in German harbors (AVERBECK, 1992b). In winter 1990/91 the percentage of oiled birds counted on German beaches went down to 14% (LÜBBE, 1993).

From 1988 to 1990, hundreds of beached birds along the North Sea coast had been contaminated with nonylphenol, dodecylphenol, vegetable oils and lubricating oils (AVERBECK, 1990; DAHLMANN, 1994; TIMM, 1991; ZOUN, 1991; ZOUN, 1992). The reasons for the chemical pollution remained unclear, although a discharge from chemical tankers had to be assumed. One particular case could only be traced to a legal discharge by one tanker resulting in 800 (counted) dead birds washed ashore (EARL, 1994a). An international effort was started by the Dutch and the German delegations within the International Maritime Organization to restrict the discharge of lipophilic substances from chemical tankers. Nonylphenol is a degradation product of nonylphenolethoxylates used to clean tanks of chemical tankers at sea which have previously transported vegetable or animal oils. However, not all seabirds oiled with vegetable or animal oils are victims of discharges from chemical tankers. A mass mortality of cormorants in 1974 had clearly been attributed to the discharge of fish oil and showed the lethal effects of such eatable oils in large volumes. The flushing of fish trawler holds and bilges has been a standard procedure at sea (BERRY, 1976).

3 Effects on Other Marine Animals

For mammals, chemical and particularly mineral oil hydrocarbon exposure may result in eye lesions such as conjunctivitis or corneal damage. Ingestion and inhalation produce inflammation of mucous membranes, lung congestion or even chemical pneumonia (NEFF, 1991). Based on toxicological experience, acute ingestion of mineral oil may lead to toxic effects e.g. in kidneys, liver, the gastrointestinal tract and in a reduction in the blood cell count. Although there are some differences in the physiology and the biochemical metabolism of chemicals, most of the rat data can be extrapolated to marine mammals and vice versa.

A large number of oil coated pinnipeds are reported (St. Aubin, 1991). After the grounding of the Exxon Valdez, it was the first time that a detailed histopathology of a number of oiled mammals had been performed before carcasses were autolyzed. Lesions characteristic of hydrocarbon toxicity (among other things neuronal swelling and necrotic neurons) in the brain (thalamus) of oiled seals 3 months after the disaster were most significant and probably explain disorientation and lethargy in seals after the spill (Spraker, 1994). Pinnipeds would seem able to detect strong chemical contamination and to leave such waters. This assumption for avoidance behavior is contradicted by observations of seals diving and surfacing in the midst of oil slicks and observations after tanker spills showing pinnipeds not abandoning rocks fouled with oil (St. Aubin, 1991). A number of reports indicate that cetaceans do not actively avoid oil either. Behavior of whales was apparently normal when observed in the oil slick after tanker spills (Geraci, 1991a). There have been a number of observations from people who saw cetaceans swimming and surfacing through floating oily slicks. Scientific judgement indicates that the filtering efficiency of whales will be reduced with a filtering apparatus is coated, but consequences have not been evaluated. Although stranded whales or dolphins were covered with spilled oil, no causal relationship could be established (Geraci, 1991a). Although otters avoid floating slicks in laboratory studies and in spill situations, their "interest" to remain in their living area seems to be stronger. After tanker spills reached their habitat, sea otters died in large numbers (Geraci, 1991b). Sea otters are particularly vulnerable to oil because they rely on pelage rather than blubber for insulation. The effect of lipophilic liquids like oils therefore resembles that on the plumage of birds: an increase of the thermal conductance decreases insulative value of the fur and produces increased metabolic rates because of the hypothermia. Their cleaning attempts lead to an oral consumption of oil. The inhalation of petroleum compounds produced general depression. Petroleum solvents and aliphatic hydrocarbons produce life-threatening episodes of aspiration inducing chemical pneumonia in men as well as in animals, often connected to vomiting if the liquids are swallowed (see Craan, 1996). The toxic effects under induced high metabolic rates and a general lack of food in the contaminated marine environment enhance the risk of death for the marine animals. After the grounding of the Exxon Valdez, the impact on sea otters was immediate, obvious and symbolic of the effects on wildlife. More than 350 otters were captured and cleaned. After cleaning the fur, otters resumed their normal appearance and behavior, but a third of all these animals which had been cleaned and treated with fluids and medicine died at a later stage. About 1,000 killed sea otters were counted. Accurate estimates of total otter mortality after the spill were not possible, but scientific estimates gave numbers between 2,800 and more than 4,000 (Ballachey, 1994). According to pathological examinations, the pulmonary emphysema induced by hydrocarbons after aspiration was one of the most important effects. Gastric erosion, hemorrhage, hepatic and renal lipidosis and hepatic necrosis had been morphological markers for the syndrome produced by the oil exposure (Lipsomb, 1994). Although many studies heavily suffered from a lack of baseline data on otters in Alaska, a few long-term effects under the continuously higher exposure to hydrocarbons were observed during the following years. Pathological examinations were severely hampered by a lack of preparation for post-spill studies and for a collection of a large number of specimens (Lipsomb, 1994). According to the results of the behavioral and pathological studies at the Exxon Valdez spill, the inhalation of short-chain and the aromatic hydrocarbons may have induced the inhalation problems, the white-spirit like aliphatic C9-C13 hydrocarbons produced pulmonary emphysema via aspiration and the resorption of C5 to C10 hydrocarbons may have caused the central nervous damages in the mammals. These results would be in accordance with results in rat and human experiences. Unfortunately, chemical analysis of mammal tissues did not measure the most toxic C5-C8 hydrocarbon fraction (Frost, 1994).

4 Tainting of Seafood

Off-flavor is considered as a warning sign, indicating above all an onset of enzymatic degradation and bacteria-associated spoilage. This is particularly true with regard to fish and shellfish. Tainting has been introduced as a technical term to designate gustatory or olfactory impairment of foods by water contaminants. Before 1980, tainting could be attributed in many cases to a long-term presence of contaminants including mineral oils in the water. Near almost all important industrial centers of Japan, a tainting of seafood was found during the 1960 - 1977 period (Ogata, 1988). Studies of tainting in an Australian bay where mineral oil products were landed by tankers revealed a kerosene-like flavor of fish (Connel, 1974). Tainting has been observed after the grounding of tank vessels. After such accidents, fishing is prohibited in the respective area for extended periods, for reasons of food hygiene and the impossibility of marketing catches. Even suspected contamination or off-flavor may result in a crash of local fish markets. Fish farming production was destroyed for two years in the Braer accident area under an agreement between fish farmers and the supervising authorities, although only a low number of fish near the site of the accident was still slightly chemically contaminated (ESGOSS, 1994). Young fish that had been introduced soon after the accident did not become tainted (Whittle, 1997). Sensory impairment can only be considered as a concomitant effect of a relatively high exposure of fish and shellfish to chemicals over a long period (e.g. as a result of caging). For cases other than those of accidental high volume discharges, "natural" reasons could be established for flavor impairment of marine animals (Höfer, 1998).

5 Ballast Water

The danger involved in ballasting ships with water is a long-known fact and lies in the transportation of pathogens, algae or other organisms (e.g. larvae) to foreign regions, thus introducing unwanted biological material during deballasting operations. Risk assessments showed that the introduction of non-indigenous organisms into the seas could have severe ecological and fishery implications (IMO, 1996b). However, it is very difficult to assess how often introduced species have actually established themselves in their new environments. There are sea areas where an introduction of foreign organisms took place in the 1970s and 1980s which led to an irreversible ecological change (CARLTON, 1993). The introduction of the European zebra mussel into the North American Great Lakes in the 1980s or the eutrophication and a massive population explosion of imported jellyfish in the Black Sea, for example, has led to tremendous changes in the regional marine ecosystem and substantial economic losses (GESAMP, 1997; TIBBETTS 1997). A study has shown that there have been over 43 newly detected exotic incursions in Australian coastal waters in one decade and a study showed that 6% of arriving vessels contained toxic species in ballast (HALLEGRAEV, 1991; IMO, 1997a). A cholera strain which causes intestinal disease, was probably carried by ballast water from Asia to Latin America and then spread to the USA contaminating oysters (TIBBETTS, 1997).

Although all ships use ballast water, volumes of ballast water in a bulk carrier are the largest in view of ship types within the world fleet. Each vessel takes in between 10,000 and 200,000 tons of ballast water. For reasons of stability, ballast water is essential for the safety of unloaded tankships in particular.

6 Antifouling Paints

Anti-fouling paints reduce the frictional resistance of hulls in the water. Tributyltin (TBT) is the main agent used in anti-fouling paints since the early 1970s to reduce the growth of organisms on ship hulls. Ships without antifouling on their hulls are estimated to have a reduction of speed or of fuel burned for propulsion both in the range of 3-10 percent.

The main cause of imposex, the development of male primary sexual characteristics in female gastropods, is the exposure of these organisms to triorganotin (STROBEN, 1993). Data indicate that commercial shipping in the open sea as well as crowded yachting in coastal waters may contribute to the occurrence of imposex (HALLERS-TJABBES, 1994). A concentration response relationship with a frequency of 100% had been found around a concentration of 20 ng/l seawater (BRYAN, 1989). The reported NOEC values for TBT are around 200-1000 ng TBT/l seawater in fish, but 5-50 ng/l in oysters. MEADOR (1997) showed a strong correlation between the toxic effect and the bioaccumulation factor BCF. Measured concentrations in the Atlantic Ocean and the North Sea are in the range of 10-3,000 ng TBT/l seawater; sediments contain even higher concentrations with an average accumulation factor of 10^3 (STROBEN, 1993). Ratio of TBT contents in marine organisms to its ambient concentrations suggest that TBT could be accumulated up to 10^4-fold.

Acceptable Daily Intake (ADI) values are decided among other things for biocides by the WHO and FAO in view of the protection of human health. Concentrations of triorganotins in the tissues of some open-sea fish and in shellfish (about 100-300 µg/kg) have exceeded the ADI value (0.5 µg/kg human body weight per day) in the past for those peoples whose diet depend heavily on sea-food like that of the Japanese (IMO, 1998c). It has to be realized that triorganotins are also used as antimicrobial agents in agriculture, textiles and plastic articles. In rats, some organotins exhibit toxic action on the blood and the central nervous system. However, studies showed wide differences in species response. According to KANNAN (1997a, 1997b), the presence of elevated concentrations of butyltins might have contributed to bottlenose dolphin mortality events in the U.S. Atlantic and Gulf coasts. Although no conclusive evidence exists yet (GREEN, 1997), such weak statistics should be noted for further research. Concentrations in the tissues of marine mammals are generally higher than those in fish.

Restrictions on the use of TBT for small ships have already been enforced and led to a significant reduction of TBT concentrations (PIDGEON, 1993). Research in Japan showed triorganotin concentration evidently decreased in traffic areas of domestic vessels after a ban on the use of TBT was enforced for such vessels. TBT concentrations revealed no notable change in similar areas for ocean-going vessels in recent years (IMO, 1998c). Reports provide evidence of partial recovery, among other things the reduction of imposex along the coastline in Europe (EVANS, 1991; EVANS, 1994). Use restrictions for pleasure craft, small vessels or domestic vessels were introduced in Japan, the USA and the European Union in the early 1990s.

7 Further Health Concerns

Toxicologists and health officials who discussed the effects of the Exxon Valdez spill raised the point: With all the attention being paid to the disaster's effect on marine animals and their environment, were the risks to humans being ignored (BARINAGA, 1989)? The cleanup chaos raised concern among union officials about a lack of training and information for the clean-up workers and of protection clothing which was often unavailable. Up to now there has been no independent assessment of the health effects of oil spills and risks involved, although there is need for it (GESAMP, 1993).

Toxic chemicals in low concentrations will not immediately kill man. However, depending on their potential to bioconcentrate when climbing the food-chain, persistent chemicals may create a hazard to man in case of chronic ingestion (BRO-RASMUSSEN, 1996). A hazard may arise in particular for fishermen and their families who are large consumers of local fish. Of special concern are a number of heavy metals and persistent organic pollutants like PCBs (NAS, 1991) or organotins (see section on antifouling paints). None of these chemicals are known to be regularly transported in large quantities or under such regulations that legal operational discharges from tankers could be of concern. No significant contamination resulting from tanker discharge could be stated. However, no statistics exist. LOHSE (1988) pointed out that an accidental release of chlorinated hydrocarbons from a chemical tanker would produce a contamination of North Sea sediments and seafood greater than the total in the 1970s produced by large-scale dumping of liquid chemical wastes.

From a health protection standpoint, the highly toxic or oily residues of vessels not allowed to be discharged into the sea pose a problem. These liquid wastes have to go to reception facilities, most of which in the world are not connected to well organized waste management systems. However, no statistics exist. It is expected that many of these wastes enter urban sewage systems of the harbor cities discharged on the seashore without any real treatment. Of special concern are non-biodegradable tank-washing residues of high aquatic toxicity, which are not allowed to be discharged from tankers into the open sea.

Scientific studies of sea pollution's impact on the health of coastal populations are scarce not because the problem is insignificant but because the victims are low-income coastal populations which inhibit countries which have limited capacities to perform scientific and epidemiological studies (GIROULT, 1995). Most of these populations have no other alternative than to use their dirty intertidal area for recreation and domestic washing, but also waste disposal and defecation.

8 Discussion

Marine birds are victims of oil discharge which enjoy prominence. However, the majority of oiled birds washed ashore are covered by machinery fuel oils. *Oil Tanker* cargo discharges, which would be illegal when causing such effects, are not responsible in general. A number of reports prove that some (legal and illegal) discharges of oils from *Chemical Tankers* killed seabirds. In a decision document, the US Environmental Protection Agency found that petroleum oils, vegetable oils and animal fats share common physical properties and produce similar environmental effects. Spills of animal fats and vegetable oils from products that linger in the environment for many years have the same or similar devastating impacts on the aquatic environment as petroleum oils (US EPA, 1997).

Severe accidents involving tankers have resulted not only in a low mortality among fish, but also in severe damage to populations of algae, mussels, crustaceans and gastropods. All reports on a large quantity of oiled marine mammals are strongly connected to the grounding of tankers. Nevertheless, such events have not yet endangered species or populations of marine animals. Far more damage to the environment is caused by phenomena which do not become apparent in this way and alter ecological balance by killing entire species of organisms, above all on the ground in the heavily oiled local area. Although an invasion of organisms takes place, the resettlement is hindered by the induced imbalances within and between trophic levels.

There are no indications that any tainting is induced by operational discharges from tank ships. The hazard is limited to large volume discharges like those which occur after tanker hull damage.

Leakages from oil tankers find an extensive coverage in the media because they produce obvious floatings and ecological damage. Oil tanker accidents are the most widely known source of ocean pollution. No *Chemical Tanker* accident producing environmental damage has yet occurred. In general, *Oil Tanker* groundings take place several times a year. However, the number of accidents and the volume spilt are decreasing (see first part of the Report on "Tankships in the Marine Environment", ESPR 2/98, pp. 97-104).

Two important aspects of global marine pollution are seldom connected to tanker traffic: 1. antifouling paints and 2. ballast water discharge.

There have been disturbances of marine ecosystems induced by the introduction of non-indigenous marine organisms transported by ships. Although no statistics exist, a large portion of ballast water is released by tankers. Although their routing is restricted to only a number of ports, some invasions reported by CARLTON (1993) are connected to such routes (e.g. Arabian Sea to Australia, Europe and Asia to the USA). The hazard created by ballast water transport and discharged pathogens has been recognized by the World Health Organization WHO, the International Oceanographic Commission IOC and the International Maritime Organization IMO (IMO, 1997b). Regulations on ballast water are in preparation under the auspices of the International Maritime Organization. Guidelines have been drafted (IMO, 1997c). A finalization of strict rules, however, will take some more years because, among other things, there are no effective means available for treating such large volumes of ballast water to render them incapable of transporting organisms or pathogens between ports. Additionally, there is no internationally accepted management strategy existing to maintain the safety of tank ships at sea while reducing the risk considerably. Coordinated research work and the preparation of regulations are ongoing (IMO 1997b; IMO 1998b).

ISENSEE (1994) estimated that tankers constitute about a third of the non-regularly emerged hull face of the world's marine merchant fleet, thus resulting in a similar important emission of antifouling agents in the open sea. However, the main emission in coastal zones is produced by leakage of antifouling from the large number of pleasure craft hulls, as long as no ban is declared. The use of antifouling-containing TBT has undoubtedly produced damage to the marine environment. Although no potent alternative to TBT exists, a ban of such antifouling would not influence the stability of vessels. It would, however, have economical effects for ship owners because of reduced speed leading to lower cost efficiency in capital investment. From a marine environment and a food hygiene standpoint, an international ban on the use of organotin-based antifouling paints is overdue.

General studies on chronic, low level effects of emitted chemicals of different origin on marine animals and in sea-bottom habitats are unavailable, including mutagenic and carcinogenic effects and their importance compared to a natural background. There is a shortage of routine environmental statistics on the organisms living in the sea, including malformed or clearly ill marine animals. Such data would enable marine scientists to evaluate the long-term impact of bulk liquid shipping and discharges more exactly.

There are a number of hazards to human health arising from marine bulk transport. Besides occupational ones, which are not covered by this review, hazards arising from the contamination of seafood with toxic chemicals emitted from antifouling or with pathogens via ballast water are predominant. There is a general lack of data concerning the health effects of discharged or spilled liquid cargo making estimations of the significance difficult. In general, even large volumes of well-diluted soluble biodegradable hydrocarbons of low toxicity discharged from tank ships will disappear from the oceans without any severe effect. Among other things, bacteria and algae provide biodegradation. A vast number of hydrocarbons will evaporate. Marine environmental problems arise with non-biodegradable liquid chemical products, the discharge of floaters in high concentration, and creation of tar-balls by oil excluding air and bacteria, thus hindering biodegradation.

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