Estimating the global burden of thalassogenic diseases: human infectious diseases caused by wastewater pollution of the marine environment

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ABSTRACT

This paper presents a preliminary attempt at obtaining an order-of-magnitude estimate of the global burden of disease (GBD) of human infectious diseases associated with swimming/bathing in coastal waters polluted by wastewater, and eating raw or lightly steamed filter-feeding shellfish harvested from such waters. Such diseases will be termed *thalassogenic*—caused by the sea. Until recently these human health effects have been viewed primarily as local phenomena, not generally included in the world agenda of marine scientists dealing with global marine pollution problems. The massive global scale of the problem can be visualized when one considers that the wastewater and human body wastes of a significant portion of the world's population who reside along the coastline or in the vicinity of the sea are discharged daily, directly or indirectly, into the marine coastal waters, much of it with little or no treatment. Every cubic metre of raw domestic wastewater discharged into the sea can carry millions of infectious doses of pathogenic microorganisms. It is estimated that globally, foreign and local tourists together spend some 2 billion man-days annually at coastal recreational resorts and many are often exposed there to coastal waters polluted by wastewater. Annually some 800 million meals of potentially contaminated filter-feeding shellfish/bivalves and other sea foods, harvested in polluted waters are consumed, much of it raw or lightly steamed. A number of scientific studies have shown that swimmers swallow significant amounts of polluted seawater and can become ill with gastrointestinal and respiratory diseases from the pathogens they ingest. Based on risk assessments from the World Health Organization (WHO) and academic research sources the present study has made an estimate that globally, each year, there are in excess of 120 million cases of gastrointestinal disease and in excess of 50 million cases of more severe respiratory diseases caused by swimming and bathing in wastewater-polluted coastal waters. Filter-feeding shellfish/bivalves, which are often harvested from wastewater-polluted areas of the sea, can effectively filter out and concentrate the microbial pathogens in the seawater. It can be roughly estimated that annually there are some 4 million cases of infectious hepatitis A and E (HAV/HEV), with some 40 thousand deaths and 40 thousand cases of long-term disability, mainly chronic liver damage, from consuming raw or lightly steamed filter-feeding shellfish/molluscs harvested globally from polluted coastal waters. The total global health impact of the thalassogenic diseases—human infectious diseases associated with pathogenic microorganisms from land-based wastewater pollution of the seas—is estimated to be about 3 million 'disability-adjusted life years' (DALY)/year, with an estimated economic loss of some 12 billion dollars per year. Due to the preliminary nature of the estimates in this study it is appropriate to assume that all of the above figures are no more than first approximations and that the true figures may be 50% higher or lower. Nevertheless, it is the author's belief that this study indicates that wastewater pollution of the sea results in a multi-billion dollar per year health burden and that preventing wastewater pollution of the sea is worthy of inclusion on the global agenda of marine pollution prevention and control.

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INTRODUCTION

It is estimated that about 50% of the world's population live in areas within a few hundred kilometres from the sea. Many of these people visit the seashore for recreation and many consume seafood harvested from marine waters. A significant portion of their human body wastes and wastewater flows, laden with pathogenic microorganisms, find their way into the world's coastal seawaters. Even the faecal body wastes from communities without any water-carried sewerage systems are frequently swept into streams and rivers during heavy rains, by surface run-off, which eventually carries these wastes into the seas.

Every cubic metre of these pollution-laden flows can carry millions of excreted pathogenic microorganisms, human-infectious doses which are the causative agents of the complete spectrum of bacterial, viral and protozoan diseases, endemic within populations in various areas of the world. Thus the coastal waters of the world, contiguous to, and in the vicinity of, human habitations are more often than not polluted with a constant daily flux of fresh human pathogens. The term *thalassogenic diseases* (thalassogenic from the Greek—caused by the sea) will be used in this paper to identify this group of infectious diseases caused by wastewater pollution of the marine environment (Shuval 1986).

It is the goal of this paper to improve on earlier estimates (Shuval 1999) and present a somewhat more advanced attempt at estimating a preliminary order-of-magnitude approximation of the global human health impact of these pathways of thalassogenic disease transmission. The ultimate goal of this paper is to stimulate the development of a more refined model and methodology for estimating the global burden of disease (GBD) of infectious diseases associated with wastewater pollution of the marine environment.

Infectious diseases associated with wastewater pollution of the sea

The following human infectious disease conditions associated with microbial pollution of faecal origin of marine coastal waters will be evaluated in this study:

(a) Infectious diseases related to bathing/swimming in wastewater-polluted marine coastal waters.
(b) Infectious diseases related to the consumption of seafood (mainly filter-feeding bivalves) harvested in wastewater-polluted marine coastal waters.

Global burden disease—a new quantitative approach for evaluating the social and economic impact of disease

For the purposes of this study the rates of each of the negative human health impacts associated with the polluted marine environment will be evaluated in terms of the concept of global burden of disease (GBD) measured in units of DALY (disability-adjusted life years) developed by the WHO and the World Bank (World Development Report 1993; Murray & Lopez 1996). Any comparison of health impacts stemming from various sources and the need to develop and invest in interventions to reduce or prevent negative impacts must start with a sense of scale of health problems. This new WHO/World Bank approach

measures the GBD by combining: (a) losses from premature death, which is defined as the difference between actual age of death and life expectancy at that age in a low-mortality population; and (b) years of loss of healthy life resulting from disability.

The GBD is measured in units of disability-adjusted life years (DALY). DALY is a term and concept which provides a useful procedure for comparing various global negative health impacts on a linear scale. It should be pointed out that the WHO team headed by Dr Murray and his staff is refining the GBD and DALY concept and methodology, and the version presented in this paper represents their earlier simplified approach which was felt to be suitable for the rough macro-preliminary type of estimate that was possible with the limited data available for this study. It is hoped that this study will stimulate future efforts to obtain better estimates of disease and the impact on various populations.

The ultimate goal of this study is to stimulate the development of a model which will provide countries and/or regions with a basis for making GBD estimates, which can serve as a reliable and rational tool for developing regional and national health policies and programmes concerning prevention of diseases caused by wastewater pollution of the marine environment.

The value of a single life, lost prematurely at age 20, has been estimated by different authors and in different countries to vary in value from $50,000 to $50,000,000. For this study, it is conservatively estimated that the money value of the economic loss of one productive year of life, or one DALY, is about $4,000. This figure approximates the global mean gross domestic product (GDP) per capita/year, but it is not necessarily based on that figure (Constanza *et al.* 1998).

INFECTIOUS DISEASES RELATED TO BATHING/SWIMMING IN WASTEWATER-POLLUTED MARINE COASTAL WATERS

Epidemiological background

There is a great deal of epidemiological evidence that enteric/gastrointestinal and respiratory diseases can be associated with bathing/swimming in marine coastal waters contaminated with pathogenic microorganisms–faecal bacteria and viruses–originating from domestic wastewater sources (Fattal *et al.* 1987; WHO 1998; Pruss 1998). The evidence from 22 credible epidemiological studies, which has been analysed by the WHO, supports the conclusion that the rate of certain enteric and respiratory infections and disease among bathers compared with unexposed non-bathers, increases steadily with increasing concentrations of indicator microorganisms of faecal pollution and have been described by a series of dose–response relationships. These studies support the conclusion that bathers face an excess attributable risk of enteric and respiratory disease among those exposed (over the unexposed), even in low level pollution of coastal waters meeting current microbial standards of the European Union (EEC 1976) and the United States Environmental Protection Agency (USEPA 1986). The dose–response relationships presented in these studies provide a sound basis for estimating the risk of infection and disease among marine bathers as a function of the microbial quality of the water. It should be pointed out that a number of enteric viruses transmitted by the faecal-oral route could cause both enteric and respiratory symptoms. While ear and eye infections are often associated with swimming and bathing in the marine environment and in fresh water, there is little or no evidence that these diseases are associated with the concentration of faecal indicator organisms or pathogens of wastewater origin in the seawater. It has been estimated that adult swimmers may ingest some 10–100 ml of seawater in 20–30 min of vigorous swimming in which they immerse their head in the water, while children may ingest even greater quantities of water.

For the purposes of this evaluation it has been assumed that the majority of bathers, throughout the world, are exposed to marine waters with medium to low levels of contamination with wastewater which, nevertheless, conform more or less to current acceptable microbial guidelines and standards (Council Directives concerning the Quality of Bathing Water of the European Economic Communities, EEC 1976; Ambient Water Quality Criteria of the US Environmental Protection Agency, USEPA 1986). We shall term such bathing beaches as 'acceptable'.

The term 'acceptable' as used in this paper refers only to the fact that these recreational waters meet current recommended standards and guidelines and are considered acceptable by most health authorities. Some might prefer the term 'tolerable' or more precisely 'traditionally accepted'.

The most credible epidemiological studies of the excess illness risk attributable to exposure to indicator organisms while bathing and swimming in contaminated marine coastal water, which are based on random controlled clinical trials with volunteers, are those of Kay *et al.* (1994) and Fleisher *et al.* (1998). These studies have been accepted by the WHO and its Scientific Advisory Committee as being the most credible and precise and are broadly supported by 22 other credible studies. They have been used as the basis for the preparation of the draft 'Guidelines for Safe Recreational-Water Environments' (WHO 1998). These studies by Kay *et al.* (1994) and Fleisher *et al.* (1998) have determined that among adults, 18 years of age and older, who actively bathed and submersed their heads in 'acceptable' marine bathing waters (and presumably ingested some sea-water) exposed to low level contamination with domestic sewage, there is a significant number of excess cases of gastroenteritis and acute febrile respiratory infections (AFRI). These waters met the current EU or USEPA microbial standards and guidelines. The average duration of illness ranged from 4 to 8 days, depending on the illness, while some 7–26% reported loss of a least 1 and up to 3 days of normal activity including absence from work, while 4–22% sought medical treatment (Fleisher *et al.* 1998).

What is the attributable risk of suffering from an excess case of gastroenteritis disease and acute febrile respiratory infection (AFRI) from marine bathing in faecally contaminated waters?

The WHO (1998) has estimated that bathing in what has been considered until now 'acceptable' marine waters, with a mean concentration of 50 faecal streptococci/100 ml (equal to the 95th percentile value), means that for every 100 healthy adult individuals exposed to a single bathing exposure in such marine coastal waters in temperate climates, there will be five clinical cases of excess enteric disease. In other words, an excess of 5% of the adult bathers with a single marine bathing exposure can be expected to become ill with gastroenteritis compared with the non-exposed. Based on the epidemiological studies of Kay *et al.* (1994) and Fleisher *et al.* (1998) and similar studies by others, it can also be estimated that there are significant levels of excess attributable AFRI, with a mean of 2%, among local adult bathers at beaches meeting 'acceptable' microbial standards and guidelines in temperate climates. Based on consultations with clinicians, it has been estimated that 1% of the adults and 5% of the infants and children reported as having become ill with AFRI after swimming/bathing in polluted water, may develop episodes of the more serious lower respiratory tract infections (LRTI). According to Murray & Lopez (1996), these episodes of LRTI can involve a mean of some 90–100 days of illness/disability and/or absence from work, with a disability severity weight of 0.28 (on a scale of 0–1). It has further been estimated by Murray & Lopez (1996) that 0.35% of the infants in the 0–4 years age group who develop cases of LRTI will develop serious life-long respiratory sequellae, such as chronic bronchitis and emphysema with a disability severity weight of 0.1 over a period as long as 60 years. Some 0.3% of the cases among such infants can result in death.

It is necessary to make a number of extrapolations and simplifying assumptions from these risk estimates in order to cover the full spectrum of sea-bathing populations and varying environmental conditions. These include bathing at beaches with no pollution or bathing in highly polluted beaches. It also includes making estimates for children and foreign tourists who are considered more susceptible than local healthy adults who carry some degree of immunity to local endemic infectious diseases.

Summary of the assumptions and estimated excess cases of gastroenteritis/respiratory disease rates caused by bathing in marine water for foreign tourists and local residents

Local residents

For adults—50% of the local population at beaches:

- *Pristine beaches*—zero excess cases of gastro/respiratory disease from bathing.

- *Acceptable beaches*—5% excess cases of gastroenteritis and 2% AFRI from sea bathing.
- *Polluted beaches*—10% excess cases of gastroenteritis and 4% AFRI from sea bathing.

For children—50% of the local population at beaches:

- *Pristine beaches*—zero excess cases of gastro/respiratory disease from sea bathing.
- *Acceptable beaches*—7.5% excess cases of gastroenteritis and 3% AFRI from sea bathing.
- *Polluted beaches*—15% excess cases of gastroenteritis and 6% AFRI from sea bathing.

Foreign tourists

For adults—50% of foreigners at beaches:

- *Pristine beaches*—zero excess cases of excess disease from sea bathing.
- *Acceptable beaches*—7.5% excess cases of gastroenteritis and 3% AFRI from sea bathing.
- *Polluted beaches*—15% excess cases of gastroenteritis and 6% of AFRI from sea bathing.

For children—50% of foreigners at beaches:

- *Pristine beaches*—zero cases of gastro/respiratory/eye disease from sea bathing.
- *Acceptable beaches*—11.25% excess cases of gastroenteritis and 4.5% AFRI.
- *Polluted beaches*—22.5% excess cases of gastroenteritis and 9% AFRI from sea bathing.

Estimate of marine bathing days and exposures/year globally

One of the more difficult parameters to estimate is the number of marine bathing days or exposures/year globally. The World Tourism Organization (WTO) has collected the official national statistics on tourist arrivals for the 40 most popular tourism destinations, which totalled 635 million in 1998 (excluding same-day visitors) (WTO 1999). Local tourism is not included in these official statistics of the WTO but are estimated by WTO experts to be as much as 10 times that of foreign tourism,

particularly visits of families to bathing beach resorts (Yunis 1999). Based on the experience of the WTO it has been estimated that only some 15% of total tourist days are spent at bathing resorts (Yunis 1999). Based on consultations with WTO experts and extrapolations from several sources it has been possible to arrive at a preliminary estimate that, world wide, there are about two billion marine bathing exposure days per year.

DALY from enteric disease contracted from bathing in polluted seawater

Based on the risk estimates and assumptions stated above, the calculated estimate of the total number of cases of gastroenteritis resulting from swimming/bathing in wastewater-polluted coastal water is 120,312,000 clinical cases/year.

Based on Kay *et al.* (1994) and Fleisher *et al.* (1998) the following assumptions have been made:

(a) Mean of 4 days of illness/incapacitation per case.
(b) Factor of disability weight = 0.05 for cases of mild gastroenteritis disease (factor of disability weight varies from 1 for total disability or death to 0.05 for very mild cases of disease).

Thus, the estimated global annual DALY from gastro-enteric disease associated with bathing in coastal waters of varying levels of wastewater pollution is 65,924, rounded up to 66,000 DALY.

DALY from respiratory disease contracted from bathing in polluted seawater

The estimated annual number of cases of acute febril respiratory infections (AFRI) and lower respiratory track infections (LRTI) are:

Total AFRI = 48,125,000 cases per year.
Total LRTI = 1,636,250 cases per year.
LRTI chronic sequellae only among children = 1,444 cases per year.
LRTI deaths only among children = 1,444 cases per year.

In order to calculate the DALY the following assumptions have been made:

(a) Mean of 6 days of illness/incapacitation per case for AFRI (based on Kay et al. 1994; Fleisher et al. 1998) and 90 days for LRTI (based on Murray & Lopez 1996).

(b) Factor of disability weight for AFRI episodes = 0.05.

(c) Factor of disability weight for LTRI episodes = 0.28 (Murray & Lopez 1996).

(d) Factor of disability weight for LTRI sequellae = 0.1 (Murray & Lopez 1996).

The calculated DALY for respiratory disease are:

AFRI eppisiodes: 39,555 DALY.
LTRI episodes: 11,297 DALY.
LTRI chronic: 5,776 DALY.
LTRI death: 57,760 DALY.

So the total DALY from AFRI/LTRI = 114,398 rounded up to 114,000 DALY.

Calculating the GBD in terms of DALY

Based on the above, it is possible to make an estimate of the GBD in units of DALY (disability-adjusted life years) associated with infectious enteric and respiratory diseases contracted from bathing at wastewater contaminated coastal beach resorts. As shown above, this estimate is based on a number of assumptions since full details of many of the input factors can only be roughly estimated. However, it is felt that these assumptions and estimates are on the conservative side. A summary of the total global DALY from marine bathing associated disease is shown in Table 1.

Economic impact

The estimated direct economic impact or financial loss resulting from this level of disease associated with bathing/swimming in wastewater-polluted coastal waters globally can be estimated at US $4,000/DALY or $724,000,000/year rounded to $700,000,000/year. However the full negative impact of marine bathing at

Table 1 | Summary of the total global DALY from marine bathing associated disease

Disease type	DALY
Gastro-enteric infections	66,000
AFRI and LTRI	114,000
Total	180,000

polluted beaches associated with infectious disease illness can have an even greater economic impact on tourism and the tourist industry than the direct health impact on the individuals involved, particularly at the more polluted, high risk locations. Resort beaches which gain a 'bad reputation' for poor sanitation/polluted waters and disease risk can face major reductions in the number of tourists.

INFECTIOUS DISEASES RELATED TO THE CONSUMPTION OF SEAFOOD/FILTER-FEEDING BIVALVES HARVESTED IN WASTEWATER-POLLUTED MARINE COASTAL WATERS

Epidemiological background

Seafood, particularly filter-feeding bivalves normally eaten uncooked, is a commonly implicated vehicle for the transmission of infectious diseases. Such disease is caused by enteric microorganisms that enter the coastal marine environment through the disposal of urban/domestic wastewater from land-based sources or ships to the sea. The first reports that typhoid fever transmission and other enteric diseases were associated with the consumption of raw shellfish harvested near wastewater outfalls in England appeared some 100 years ago (Soper 1905; Stiles 1912). According to Eyles (1986), seafood is involved in an estimated 11% of all the food-borne outbreaks in the USA, 20% in Australia and over 70% in Japan, where eating raw seafood is more popular. According to a report by the Communicable Disease Surveillance Centre of the UK

(Scoging 1991), fish, shellfish, and their products are responsible for a significant portion of all food-borne diseases world wide.

Pathogenic bacteria can remain viable in the sea for weeks and viruses can survive in the marine environment for months, adsorbed to organic particles or in the tissues of fish and seafood. The particularly virulent infectious hepatitis A virus (HAV), which has caused many validated shellfish-associated outbreaks, can survive in the sea for over a year (Gerba 1988). Filter-feeding bivalve shellfish/molluscs such as oysters, mussels, clams and cockles are particularly susceptible to bacterial and viral contamination since they feed by sieving large volumes of seawater, many times their own weight, and concentrate and retain food particles, including faecal particles containing pathogenic microorganisms. Such filter feeders can concentrate bacteria or viruses from the environmental waters so that the concentration in the shellfish meat can be over a hundred times greater than that of the ambient seawater from which they were harvested. Thus, such shellfish filter-feeders, whose breeding areas are often located near sources of nutrients such as wastewater outfalls or polluted estuaries, are particularly prone to concentrate high levels of pathogens. This hypothesis has been validated in many field studies which have assayed the virus concentration in samples of the meat of freshly harvested shellfish from marine waters. A series of studies involving the assay and detection of viruses in shellfish in Mississippi, New York, North Carolina and Texas, detected enteric viruses in 19% of 58 pooled samples. The shellfish which were sampled, taken from waters meeting current United States bacteriological standards for shellfish growing and harvesting, had a mean virus concentration in the shellfish meat of 10 PFU (plaque forming units or tissue culture infectious units)/100 g of shellfish meat (Metcalf & Stiles 1967; Metcalf & Melnick 1976), as reported by Rose & Sobsey (1993). Denis (1973) reported that in a survey of enteric viruses in shellfish in the Paris open fish market in 1978, some 25% of the shellfish sampled were contaminated with pathogenic enteroviruses. Despite all the advances in standard tissue culture virus assay and detection techniques, most studies indicate that, at best, they can detect and recover only 50% or less of the viruses present. This would suggest that the

actual presence of viruses in harvested shellfish samples in the study areas was actually even higher. From evidence gained at various outbreaks and laboratory studies, it has been estimated that the minimal infectious dose of HAV for humans is very small—in the range of 1–10 PFU. It is also estimated that 75% of adults infected with HAV end up with a clinical case of infectious hepatitis. This is mainly true for those areas of the developed world where the levels of HAV immunity are relatively low.

Many of these shellfish are eaten raw or steamed lightly and can easily cause infection and disease. Both laboratory and field studies indicate that light steaming rarely heats all of the flesh of the shellfish to temperatures which are necessary to effectively and totally inactivate all or most of the pathogenic agents (Koff & Sears 1967). Thus, from a public health/disease-risk point of view the consumption of both raw and lightly steamed shellfish is a potential source of serious infection and disease (Gerba 1988).

Infectious hepatitis A (HAV), a serious disease of the liver, is frequently transmitted by shellfish. According to Cliver (1997) HAV is 'notoriously under-reported' in the United States despite the fact that it is a legally reportable disease. What was at first called non-A, non-B hepatitis is now known to be a series of additional infectious hepatitis viruses including types C, D, E and possibly F. More is known about HEV, which has the same faecal-oral and environmental routes of transmission as HAV and has caused numerous serious water- and food-borne outbreaks. This includes the 40,000 drinking water-borne cases of HEV in Delhi, India, in 1954, and the outbreak with more than 100,000 cases in 1986–88 in the Xingjiang Uighar region of China. HEV is particularly virulent, with much higher rates of death and complications such as permanent liver damage, than HAV. Fatality rates for pregnant women of 20–40% have been recorded. There are numerous reported investigations of outbreaks of HAV transmitted by eating shellfish (Goldfield 1976; Desenelos et al. 1991). One recent dramatic example is the major massive HAV or possibly HEV outbreak associated with eating raw shellfish which occurred in Shanghai in 1988 (Halliday et al. 1991) resulting in some 300,000 cases including numerous deaths and permanent liver damage.

Both hepatitis A and E viruses are listed as 'Severe Hazards' in Appendix V of the 1995 USFDA Food Code. Both HAV and HEV virus are excreted in faeces and are poorly removed, even by so-called 'complete or full' wastewater treatment processes. Heavy chemical disinfection of the final wastewater effluent with chlorine or ozone can partially reduce the concentration of HAV/HEV. Nanofiltration of wastewater effluent can most probably completely remove all viruses. However, most wastewater treatment plants, even in developed countries do not provide effective disinfection or nanofiltration which would totally inactivate or remove HAV/HEV in the wastewater effluent disposed to the sea. These pathogenic viruses can survive for months if not years in the marine environment and in fish and shellfish (Gerba 1988).

Conventional depuration techniques, used to aid in cleaning shellfish harvested in polluted waters, where shellfish are held in clean, disinfected water tanks for 36–48 h for so-called self-cleansing, are only partially effective in removing bacterial contamination, but are even less so with viruses which are tightly adsorbed to the internal tissues of the molluscs (Cliver 1997).

People ill with HAV may be seriously incapacitated and bed-ridden for up to 3 months or more and in some cases require up to 6 weeks of hospitalization. The death rate in the cases of HAV in developed countries is about 0.6–1%. The rate can be higher among the malnourished, weak and elderly, particularly in developing countries. There is some permanent damage to the liver in about 10% of the cases, with major lifelong disability which leads to serious lifelong suffering and physical limitations ending at times in cancer of the liver and other causes of premature death (Grabow, personal communication 1998).

Sporadic transmission of infectious hepatitis during non-epidemic periods

Although there have been numerous reports of outbreaks of HAV associated with eating shellfish, it can be assumed that sporadic cases of HAV and HEV are seriously under-reported and if reported, are often not recognized as being associated with eating raw shellfish. In addition to the frequent findings of pathogenic enteric virus concentrations in fresh market shellfish, there is epidemiological evidence that there are numerous sporadic cases of HAV transmission from eating raw or lightly steamed shellfish. In the study by Koff *et al.* (1967) it was reported that some 20% of all the cases of HAV, during non-epidemic periods, hospitalized in a group of Boston hospitals were apparently associated with the ingestion of raw or lightly steamed shellfish. Similarly, a study in England found about 25% of the reported infectious hepatitis cases had consumed raw or lightly steamed shellfish prior to the period of incubation of the disease (Scoging 1991). Gerba (1988) reports that some 20% of all the clinical HAV cases in the United States are associated with eating raw or lightly steamed shellfish. It must be remembered that the reported and/or hospitalized cases of HAV represent only a portion of the actual number of cases of the disease, due to under-reporting.

It is thus concluded that, in addition to the numerous known epidemic episodes of HAV and HEV transmission by shellfish, there is a steady rate of endemic/sporadic transmission of individual cases spread widely among the millions of regular consumers of raw or lightly steamed molluscs among residents in both developed and developing countries, and the many hundreds of millions of tourists to seaside resorts where freshly caught seafood is one of the food attractions.

The scientific basis for the quantitative risk assessment associated with consuming shellfish

Professors Joan Rose and Mark Sobsey, who have carried out important basic theoretical and applied research in developing quantitative risk assessment methodology for environmentally transmitted microbial diseases, have written the seminal work to develop the methodology for the quantitative risk assessment associated with exposure to virus contamination in shellfish (Rose & Sobsey 1993). For the purposes of this study the Rose-Sobsey method has been adopted and used for the assessment of risk of infection and disease from consuming raw shellfish.

Rose & Sobsey (1993) concluded, based on the average virus levels detected in shellfish from all studies in the

United States, that individuals consuming a single serving of raw shellfish of about 60 g, from approved waters in the United States containing an estimated 6 PFU (plaque-forming units) of virus, may have a 1 in 100 probability of becoming infected with a moderately infectious enteric virus such as HAV. In other words, they have estimated that 1% of those who eat a 60 g serving of raw shellfish can be infected. This risk estimate is limited primarily to HAV risk associated with eating shellfish in the United States. It is not unreasonable to assume that these findings also apply to the rest of the developed countries of the world. HEV virus, which is particularly virulent, is known to cause massive water-borne and shellfish-borne epidemics in Asia, the Middle East, Africa and parts of South America. In those regions HEV is the most common cause of acute hepatitis in adults.

The infectivity rate of HEV is considered to be higher and may likely be closer to that of rotavirus which, according to Rose & Sobsey (1993), may reach 40%. Rose & Sobsey (1993) did not relate to the higher risk of infection of HEV since it is not normally considered endemic in the United State. However, since the extremely virulent HEV, with its high rates of damaging sequellae, is endemic in some two-thirds of the world and its mode of infection through water and shellfish is the same as HAV, it is not unreasonable to assume that a significant portion of the persons exposed to shellfish meals globally may ingest the more virulent HEV virus. It is also assumed that many of the shellfish-harvesting areas in Asia, Africa, South America and the Middle East are more contaminated with raw or only partially-treated urban wastewater than the approved and inspected shellfish-growing areas in the USA. Fresh iced shellfish from those areas are distributed daily by air-freight throughout the developed world.

For this study it has been estimated that the rate of HAV/HEV illness globally among those who consume a raw shellfish meal of some 120–150 g from slightly contaminated sources or worse, is 1 in 200 or a rate of 0.5%, which is half the rate of 1.0% for HAV estimated by Rose & Sobsey (1993) for a shellfish meal of 60 g. Thus, in effect, the risk estimate used in this study is conservative and about one-quarter of that made by Rose & Sobsey (1993).

Estimate of the global production and consumption of molluscs

The estimated global consumption of molluscs is drawn from the production/catch data of the FAO fisheries statistics database—FISHSTAT (FAO 1997). From this database it can be calculated that the world catch of molluscs of all types reaches some 10 million metric tons. This estimate has been used for this evaluation of the GBD associated with eating shellfish harvested in polluted marine waters. It has been estimated that 80% of that figure, or some 8 million metric tons of the molluscs, reach the market, i.e. oysters, mussels, clams and cockles which are of the type that are normally eaten raw or lightly steamed. It is also assumed that only 10%, or some 800,000 tons of filter-feeding shellfish which are eaten raw or lightly steamed, are grown and harvested in marine coastal areas and/or estuaries adjacent to urban areas which dispose of raw, partially-treated, or even so-called fully-treated wastewater to the marine environment and can thus be considered potential carriers of pathogenic microorganisms, particularly HAV and HEV.

In order to estimate how many mollusc meals or servings are consumed globally it has been estimated that about 15% of the shellfish weight is actual meat, so that 1 kg of gross weight of shellfish is required for an average meal of 150 g of shellfish meat (James 1999). From the above it can be estimated that some 800,000,000 human meals/serving equivalents of contaminated and potentially infectious filter-feeding shellfish are consumed globally each year.

Calculating the GBD in terms of DALY

Based on the above estimates/approximations and assumptions it is possible to make a preliminary estimate of the GBD, in units of DALY, associated with infectious diseases contracted from the global consumption of shellfish/molluscs eaten raw or steamed. At this stage the estimate is limited only to HAV and HEV infections since these two diseases are by far the most serious ones associated with shellfish transmission. This estimate of the GBD, based on HAV/HEV alone, will also be based on a number of simplifying assumptions and approximations, since full

details of many of the input factors can only be roughly estimated at this time. In general it is felt that these assumptions are on the conservative side. The following assumptions have been made:

(a) Of those exposed to contaminated raw or steamed shellfish harvested in approved, but lightly contaminated marine waters or more contaminated waters, the mean global HAV/HEV disease rate of those exposed is estimated at 0.5%.
(b) The mean length of severe disability and/or hospitalization of an acute clinical case of HAV/HEV is 90 days.
(c) The death rate globally among cases of HAV/HEV is 1:100 or 1% and the rate of permanent damage to the liver or other sequellae is 1:100 or 1%.
(d) Average age of onset of illness is assumed at age 20 (40 years of discounted life remaining).
(e) Factor of disability weight for acute stage of disease = 0.5.
(f) Factor of disability weight for chronic/life-long disability stage = 0.5.

Clinical cases of disease

Based on the above assumptions and estimates the following estimates can be made:

Infection with HAV/HEV: 4,000,000 cases per year.
Permanent disability: 40,000 permanent disability cases per year.
Deaths: 40,000 deaths per year.

Effects of disease estimated in units of DALY

Cases of HAV/HEV per year: 493,150 DALY.
Cases of disability: 800,000 DALY.
Deaths per year: 1,600,000 DALY.
Total HAV/HEV from shellfish: 2,893,000 DALY rounded up to 2,900,000 DALY.

Effects of disease estimated in US dollars

The estimated economic impact or financial loss resulting from this level of disease can be estimated at US$4,000/ DALY or 11.6 billion dollars/year, rounded up to 12 billion dollars/year.

CONCLUSIONS

This paper presents a preliminary order-of-magnitude estimate of the global burden of disease (GBD) associated with swimming/bathing in wastewater-polluted coastal waters, and with eating raw or lightly steamed filter-feeding shellfish/molluscs harvested from such waters, polluted with pathogenic microorganisms of faecal origin. These infectious diseases, related mainly to pathogens carried by land-based sources of wastewater pollution of the seas, have been called thalassogenic diseases in this paper. Until recently these human health effects, associated with pathogenic microorganisms mainly from land-based sources of sewage disposed into the marine environment, have been considered to be primarily of a local nature and have not been included in the world agenda of marine scientists dealing with global marine pollution problems.

The massive global scale of the problem can be visualized when one considers that human body wastes, which carry the full spectrum of microbial pathogens of a significant portion of the world's population, about 50%, who reside along the coastline or in the vicinity of the sea, are continuously being discharged directly or indirectly into marine coastal waters, much of it with little or no treatment.

This study has estimated that globally, foreign and local tourists together spend some 2 billion man-days annually at coastal recreational resorts and are often exposed there to these wastewater-polluted coastal waters. It has been estimated that annually the world population consumes some 800 million meals of potentially contaminated shellfish and other seafoods grown and/or harvested in wastewater-polluted coastal waters. Based on risk assessments from the WHO and academic research sources it has been estimated that globally, each year, there are some 120 million excess cases of gastro-intestinal disease and some 50 million excess cases of the more severe respiratory diseases caused by swimming in wastewater-polluted waters. It has also been estimated in this study that there are some 4 million cases of infectious hepatitis (HAV/HEV), with some 40 thousand deaths and 40 thousand cases of long-term disability annually from consuming raw or lightly steamed shellfish/molluscs harvested from wastewater-polluted coastal waters.

The total estimated impact of the human disease associated with land-based marine pollution by sewage is about 3 million disability-adjusted life years (DALY) per year, with an estimated economic loss of some 12 billion dollars per year. If one compares these estimates with estimates for other known diseases of global public health importance for which DALY have been calculated by Murray & Lopez (1996), it can be seen that the loss of life years and their associated economic loss estimated to be caused by marine pollution from land-based sewage is very significant, with the impact being similar to that of upper respiratory tract infections and intestinal nematodes world wide.

It is necessary to note here that all of the above estimates are at best only first approximations which must be taken with reservation and used with caution. The approach used is macro in scale with many simplifying assumptions, extrapolations and approximations. Thus it is appropriate to assume that all of the above figures are no more than rough order-of-magnitude estimates and that the true figures may be 50% or so greater or less. While the methodology used may serve as an illustration of how one might go about estimating the global impact of disease associated with polluted marine coastal waters it must be refined if more accurate and dependable estimates are to be made.

However, hopefully these preliminary estimates may serve as a basis for determining an order of magnitude of these problems which are undoubtedly of global scope and which have massive health and economic implications in the multi-billion dollar range every year. These estimates suggest that these diseases add up to an issue worthy of inclusion on the global agenda of marine pollution prevention and control.

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