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# Global Contamination Issues Emerging in Coastal Regions: Implications for the Red Sea Ecosystem

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Abstract. Coastal waters in tropical and sub-tropical regions of the world are among the most productive and intensely commercialized marine ecosystems, and are also the most threatened by contamination from industrial and urban land-use activities. Insights into issues of potential importance for the Red Sea area may be obtained from experiences in analogous waters elsewhere in the world, including the western hemisphere. Globally, the major challenges to a healthy coastal environment are posed by urbanization/industrial activity, intense coastal shipping, offshore petroleum exploitation, and tourism development. Although the Red Sea is characterized by low population densities along its coasts, the need still exists for proper coastal zone management. Urbanization and industrial activity are the major factor in pollution by metals in the vicinity of the city of Jeddah as well as by effluents from desalination plants and refineries. Such urban-generated contamination almost always goes together with contamination by sewage and nutrients from waste water treatment. All can have a negative effect on valued coastal amenities such as coral reefs, bathing beaches, coastal fisheries/mariculture, and coastal mangroves. Research in Lake Ontario, Canada can be used to provide means to study the dispersal of such pollutants via sediments. Ships using the Suez Canal carry cargoes (some of which are toxic or harmful to aquatic life) that pose a threat to coastal resources by accidental and deliberate spills/discharges. Research carried out elsewhere (the Bahamas) into the fouling of tourist beaches by petroleum tar-balls has shown that this effect is serious and cumulative and, in addition to sensitive coastal amenities (beaches, coral reefs, and fishing grounds), might also cause damage to valued benthic communities. Ships traversing the Red Sea also have the potential for introducing exotic species from remote areas that may be harmful to the diverse Red Sea aquatic fauna, especially *Acanthaster planci*, the crown-of-thorns starfish. This possibility is dramatically illustrated by the case of the inadvertent introduction of the European zebra mussel (*Dreissena*) to the Great Lakes in 1986.

## Introduction

Coastal waters, the transition area between the open sea and the land, absorb much of the impacts of human activities. They are subjected to multiple and often conflicting uses, ranging from recreational beaches and resorts, to fishing, to consumptive uses, to use as receiving waters for municipal and industrial wastes. As a result, they are the most threatened by contamination from industrial and urban land-use activities and from a variety of other environmental problems. This is true whether these waters are located in tropical and sub-tropical regions such as the Red Sea, or in the temperate northern regions of the world. The Red Sea is, in many ways, still a pristine ecosystem, as yet little stressed by human activities. However, it is hoped that by being aware and watchful for some of the avoidable problems encountered elsewhere, that this environmental situation could be preserved. This report will discuss some of these coastal contamination problems, from the perspective of research done on the Great Lakes of North America and in the Caribbean, and suggest parallels between these ecosystem and that of the Red Sea. The research all focus on the use of the bottom sediment record as a means of determining the impact and dynamics of contaminants in the coastal zone.

### *The Laurentian Great Lakes*

The Great Lakes of North America (Fig. 1) were formed in the Pleistocene epoch by glacial occupation and deepening of existing drainage systems. These lakes represent the largest fresh-water body in the world, a property that contributed to their present status as centres for North American agriculture, industry, and transportation. During the shipping season, scores of ships use the St. Lawrence Seaway, an aquatic sea-corridor bringing marine ships more than 3000 km into the heart of the North American continent. The coastal zone of these lakes now is home to an estimated 20 million people, most of whom live in fewer than 8 cities in the United States and Canada. The conflicting uses of this large reserve of fresh water by an increasing population has created a number of environmental problems, which are now the subject of intense research and remediation by the governments of Canada and the United States.

### *The Red Sea*

In sharp contrast to the Great Lakes, the Red Sea is a marine body of water located in the subtropical zone within an area most properly described as desert. Almost twice the area of the Great Lakes combined (Fig. 2), it forms a single, elongated body more than 2000 km long. It was

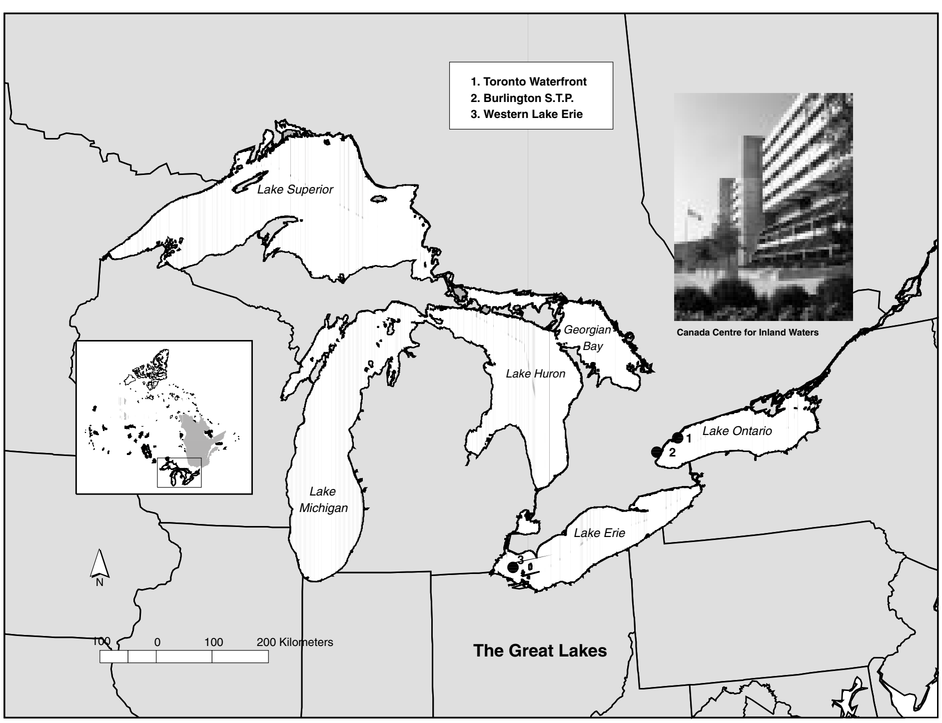


FIG. 1. The Great Lakes of North America are the largest body of fresh water in the world and are situated on the border between Canada and the United States of America. The numbered solid dots mark areas where the Great Lakes research mentioned here was carried out.

Top inset : The Canada Centre for Inland Waters, in Burlington, is Canada's foremost centre for aquatic and environmental research.


FIG. 2. The Red Sea is located in the Middle East region, occupying a rifted depression between the African and the Asian continents. It is surrounded by 8 countries. Major ports are Jeddah, Saudi Arabia and Port Sudan.

Top Inset: The Red Sea compared in area with the Great Lakes of North America.

formed as a result of relative vertical movements of crustal plates (it is a continuation of the East Africa rift system) separating the African and Asian continents. Because of the associated tectonic down-faulting, its maximum depths, more than 2000 m, are much greater than in the Lakes. The Red Sea is bordered by Egypt, Saudi Arabia, Sudan, Djibouti, Ethiopia, Yemen, and Jordan (Fig. 2), but population density along its coast, with the exception of Jeddah (1.25 million people) and Port Sudan (300,000 people) is relatively low. As a result, the Red Sea remains overall an extremely pristine environment with the largest diversity of aquatic life of any body of water in the world. However, the above population centres nevertheless contribute much to the environmental stresses on the coastal Red Sea (industrial and municipal waste discharges, petroleum discharges and spills, brine disposal from desalination plants, coastal zone abuse, to name a few). Other significant industries in this regard are those associated with petroleum exploitation (transport and refinery) and shipping through the Suez Canal that connects the Red Sea to the Mediterranean. The most valued coastal ecosystems are the abundant coral reefs and bathing beaches that attract large numbers of divers and tourists, primarily to resorts in Egypt, although mangroves also provide valuable sites for coastal wildlife.

### *The Bahamas*

The Bahamas archipelago is located in the western Atlantic Ocean within 200 km from the coast of Florida (Fig. 3). It comprises over 700 islands and cays, of which only 19 have sufficient water supplies to be inhabited. The islands are composed entirely of coral sand derived from reef material and carbonate deposition on the shallow banks. The principal industries are offshore banking and tourism, although there is an increasing diversification into light industries (petroleum refining and trans-shipment, cement production and fish processing), most of which are located on the islands of Grand Bahama and New Providence/Nassau. The overall pristine condition of the Bahamas aquatic environment, like that of most of the Red Sea, is the main component in a steady growth in the areas of underwater recreation and eco-tourism. Plans are also under consideration to initiate mariculture as another industrial initiative.

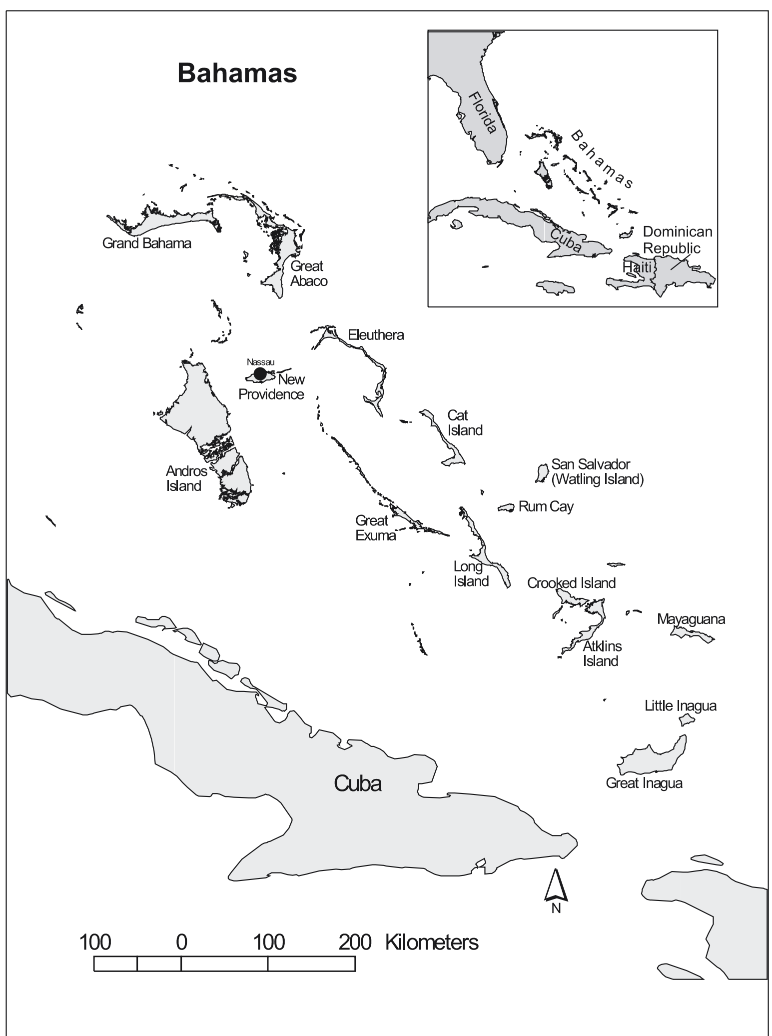


FIG. 3. The Bahamas archipelago lies between Florida and the Dominican Republic. Most of the economic activity and tourist visits take place in the capital, Nassau.

To provide for its population of 280,000 and a transient tourist population of up to 3.5 million per year, the capital island, New Providence, must rely on desalination plants and inter-island water shipments to supply more than 2 million gallons per day. The waste brines from this plant are discharged into deep wells located close to the south shore of the island.

After relying on in-ground septic systems until recently, much of the island's sewage now undergoes partial treatment before being discharged into deep wells located on the north shore close to the harbour (Fig. 4). Given the porous nature of the limestone bedrock, it is noteworthy that no studies are available on the effect of both these discharges on sensitive environmental amenities located nearby, in particular, coral reefs, bathing beaches, and fish retention facilities.

## Coastal Environmental Problems of a Global Nature

### *Coastal contamination in the Great Lakes*

Environmental problems affecting the Great Lakes that might have relevance to the Red Sea environment are:

- Contamination of coastal waters, beaches and commercial marine species by effluents from human activities (sewage treatment plant discharges)
- Invasion of aggressive alien aquatic species (Zebra mussel impacts)

There are a variety of vectors for inputs of contaminants to the coastal zone of the Great Lakes. Non-point sources include surface run-off from agricultural areas using chemical fertilizers, pesticides, and herbicides. A major non-point source is the atmosphere, which is the main vector for long-range transport of pollutants; these affect mostly the larger-area deep-water zones of the lakes. Point-sources, however, are the most important for the nearshore zone, and will be the focus of this report. Such sources include inputs from municipal sewage treatment plants and industrial discharges.

### *Sediment Tracer Studies in Lake Ontario*

In management of coastal resources, it is critical to identify the zones of influence (mixing zones) of known point-source contaminant inputs. In the Toronto area the largest point-sources for contaminants are the Main and Humber Sewage Treatment Plants (STP) and the Humber River (Fig. 5). The Hamilton area to the southwest represents another

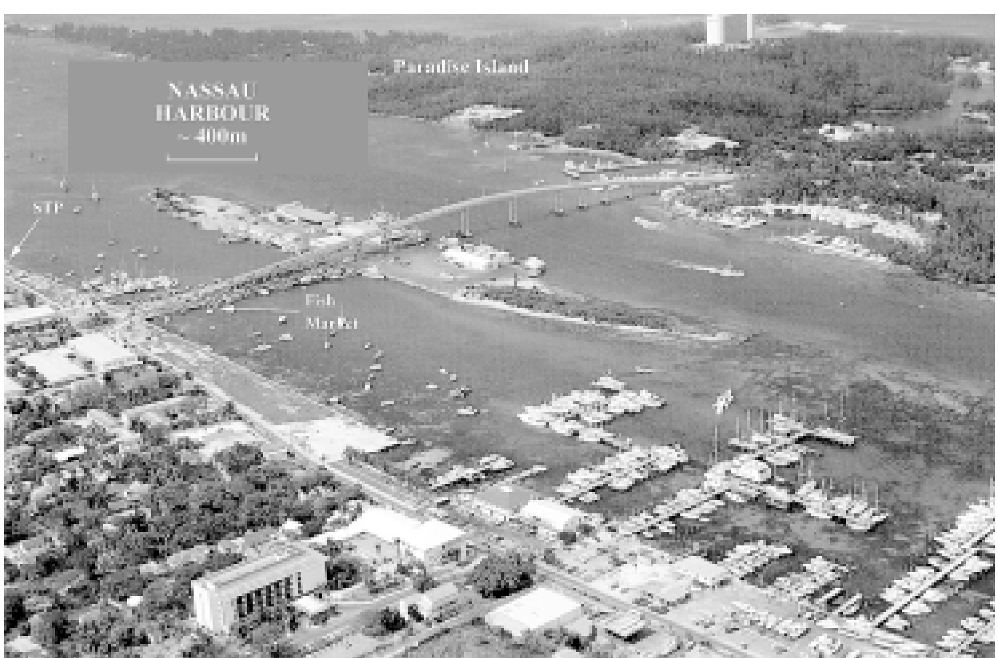


FIG. 4. Oblique aerial photograph of Nassau Harbour to the north of the island. The bridge shown connects Nassau to Paradise Island, a major tourist destination. Note the proximity of the sewage treatment plant installation (STP) to the local fish market.

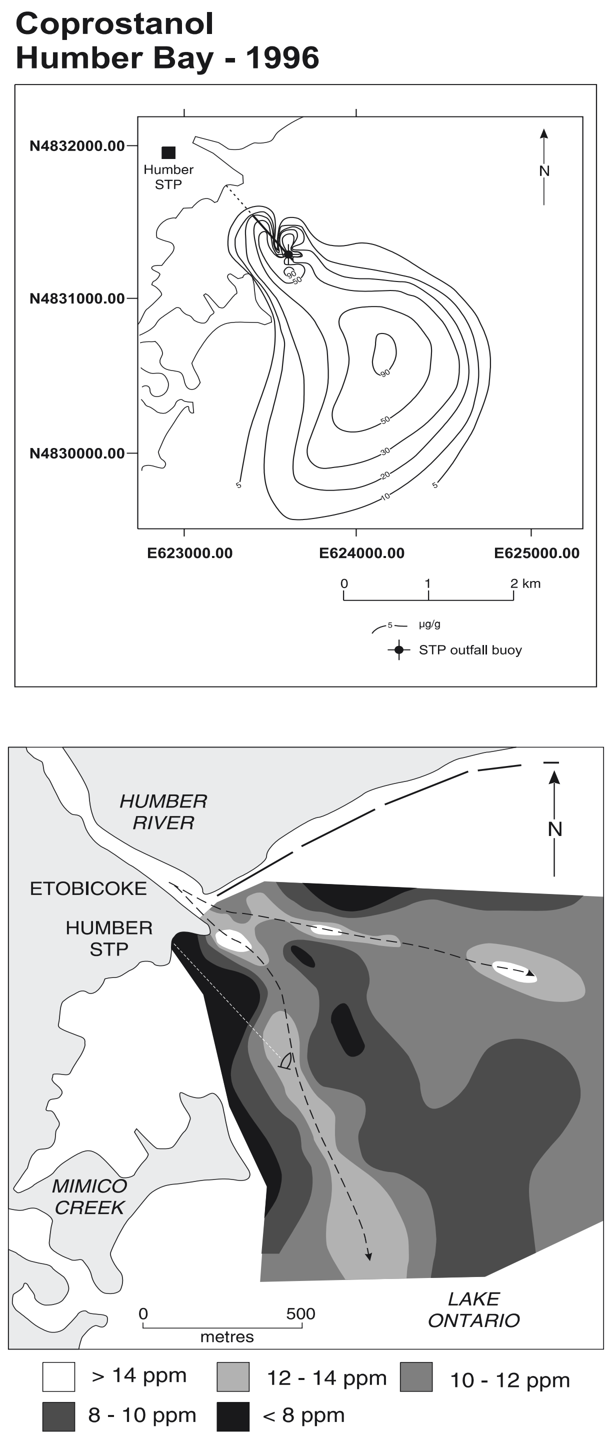


FIG. 5. Tracer studies in the vicinity of two major sources of contaminants to the Toronto waterfront, nearshore Lake Ontario (location 1 in Figure 1).

Top: Transport pattern of sediment contaminated by sewage effluent from the Humber Sewage Treatment Plant (STP) outfall, using as a tracer, the conservative faecal sterol, coprostan ol. Inferred flow is to the south and southwest around the headland.

Bottom: Use of bottom sediment concentrations of cobalt, released by metal-working industries in the Humber River watershed, as a tracer of sediment transport patterns near the mouth of the river. Pattern shows two principal modes of transport.

important point source of sewage and industrial discharges. Tracer studies were carried out in both areas, *i.e.*, the vicinity of the Humber STP and the river mouth in the Toronto area, and at the outfall for the Burlington Skyway STP in the Hamilton area (Fig. 6). The aim was to determine whether the effluent plumes constituted a threat to clean-water amenities, such as nearby drinking-water intakes, bathing beaches, and fish spawning areas.

*Methodology*

The methodology of the studies is described in the publications listed below, but is summarized briefly here. In the Toronto study, statistical analysis of a selected suite of trace metals Coakley and Poulton (1991) was used to identify the principal point sources, the Humber River and the Humber Sewage Treatment Plant (STP) outfall. Dispersal of contaminated sediments from the river was investigated using as tracers a cesium-containing mineral, as well as naturally-occurring trace metals. The cesium tracer mineral is inert and non-reactive and is conservative over the study period. In the case of the STP effluent, an array of conservative sewage-related compounds was used to trace the outfall dispersion; these included the fecal steroid, coprostanol (Bachtiar *et al*., (1996) the vitamin-E compound, a-tocopheryl acetate, and stable isotopes of nitrogen and carbon (Coakley *et al*., (1992).

Sediment samples were collected in a systematic grid pattern around the point sources and analyzed for the above tracers. Analysis of organic compounds was by gas chromatography/mass spectrometry. For trace elements, some were analyzed by standard ICP atomic emission spectrometry and others (cesium) by neutron activation analysis, using accepted standards of quality control and quality assurance (QA/QC). The concentration of the various tracers was plotted onto maps of the area and contoured to identify spatial distributions, patterns, and concentration gradients. These were then interpreted in terms of contaminant transport plumes.

*Toronto Waterfront (Humber Bay)*

The dispersal patterns inferred for the discharge from the Humber River are shown in Fig. 5 (Bottom). There appear to be two distinct patterns, one resembling a jet pattern pointing directly offshore, while the other follows the western shore of the Bay in a southward direction. A net southward transport plume along the western shore of the Bay

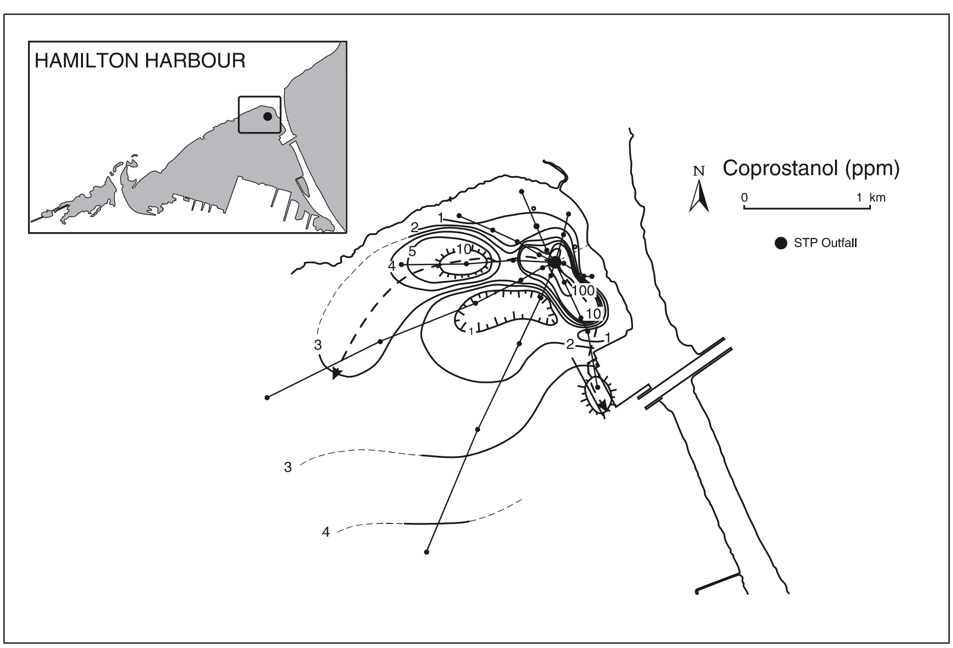


Fig. 6. Transport pattern using the tracer, coprostanol, around the Burlington Skyway STP outfall (location 2 in Figure 1). Radial sampling grid and sample locations of bottom samples are shown. Dotted lines shows interpreted contaminated sediment transport patterns. Inset shows relationship of study area to Hamilton Harbour, a major inland industrial.

was also visible in the coprostanol pattern around the STP outfall (Fig. 5 Top). However, significant flow reversals toward the northeast were identified (Coakley *et al.*, 1992). This reversed pattern is important in that sensitive areas (beaches) are located in that direction; however, this pattern is relatively minor, and in general, the plumes were in directions away from sensitive areas .

*Hamilton Harbour and Western Lake Ontario*

Dispersal patterns associated specifically with sewage discharges from the outfall of the Burlington Skyway STP within Hamilton Harbour were investigated using coprostanol as a tracer. A distinctive shore-parallel plume, having a principal southward trend was identified, with a secondary transport direction toward the north and west (Bachtiar *et al.*, 1996). In connection with plans to relocate the outfall from the Harbour to the open lake, another study was carried out in the vicinity of the new outfall site using an artificial tracer similar to that used in the Humber River study. The results showed that transport in this area was at a low rate under summer conditions and the tracer was displaced only a short distance from the origin over a period of three months. This is indicative of a relatively low mixing capacity at that particular site, and suggests further search for another more energetic site.

***Coastal Contamination in the Bahamas***

Coastal contamination has not been extensively studied in the Bahamas, largely because the general perception is that it is not a problem. While this is generally true, there are some environmental issues impacting the coastal zone that merit attention, and also could have relevance to coastal issues in the Red Sea area, namely:

- **Pollution of bathing beaches by oil residues** from production and shipping of petroleum.
- **Placement of conflicting facilities,** such as sewage treatment plant outfalls and areas of mariculture or temporary fish-retention areas.

***Tar Balls on Bahamian beaches***

Many of the beaches in the Bahamas, especially on the island of Grand Bahama (the locus of petroleum trans-shipment and refining, as well as intense tourist development), are contaminated to a greater or lesser extent by petroleum residue. This pollution, commonly referred to as "tar balls", occurs in the form of semi-solid, flattened, rounded masses, generally less than 10 cm in maximum dimension (Fig. 7). These are recognized as global phenomena and as alarming indicators of world-wide pollution of the oceans and coastal waters by petroleum discharges of various types (accidental spills, irresponsible discharges of tanker washings and coastal zone

FIG. 7. Tar balls, rounded desiccated masses of crude petroleum, are found commonly on many Bahamian beaches, causing concern especially in tourist areas. They are most often associated with masses of seaweed stranded on shore at high tide.

oil production). In the Bahamas, the economic and aesthetic impact on tourist amenities is considerable, as these tar balls attach themselves to the feet and clothing of sun-bathers and are brought inside to damage carpets and flooring. The tar balls that settle on the sea-bottom may also affect the health of benthic organisms and bottom-feeding fish. The phenomenon has been studied in only a few places, mostly in the Caribbean (Coakley, 1977 and Dennis, 1974) but represents a potential contamination problem for petroleum production, refining, and shipping areas such as the Red Sea.

In a beach survey carried out in 1976, the number of tar balls at 19 beach sites on the south coast of Grand Bahama were estimated. Bulk samples of the top 5 cm of beach sand were collected at the high-water mark using a square quadrat sampler 0.25 $m^2$ in area. The sand was passed through a sieve with a mesh size of 6.4 mm, and the tar balls separated, weighed and counted. The results demonstrated that the tar balls were highly variable in size and degree of weathering. The beaches averaged 50 tar balls or 24 $g \cdot m^{-2}$ (*i.e.*, balls larger than 6.4 mm). Statistical analysis on the distribution of these contaminants was inconclusive as to their origin, but their overall weathered state suggests that they were not derived locally but originated far away, possibly as discharges of tank-washings along the tanker shipping lanes off the west coast of Africa.

### *Contamination from Sewage?*

Like most growing metropolitan areas, the Bahamas is constantly upgrading its waste water treatment infrastructure. The present location of the main STP for Nassau, the capital was located on the north shoreline, adjacent to the harbour (Fig. 4). This site is within a kilometre of the newly relocated fish market with its extensive holding areas for live shellfish, turtles, and grouper (Fig. 8). Within a short time, there were frequent outbreaks of gastro-intestinal complaints from customers of the fish market, and a bacteriological survey was initiated. The results pointed to the STP as a possible source of harmful bacteria, which were reaching the market area and contaminating the live fish. This is especially serious considering that much of the shellfish sold (conch) is consumed raw. This case illustrates clearly the need to conduct prior surveys of hydrodynamic mixing and current patterns before locating STP outfalls or clean-water facilities within reach of each other.

### *Zebra Mussel Impacts in Western Lake Erie.*

Zebra mussels (*Dreissena polymorpha*, ZM) are bivalved mollusks native to fresh and brackish wa-

FIG. 8. Fish being processed at the Nassau fish market. This market is located within several hundred metres of the major STP for the city. Holding and aeration tanks are visible at the top left of the photo.

ter areas of eastern and northern Europe. Adults normally reach sizes (maximum shall length) of up to 25 mm (Fig. 9). They are encrusting by nature and form thick, strongly-attached coverings on any submerged hard surface available (Leach, 1993), including intake pipes of cooling water systems for coastal installations and ships, and the surfaces of navigation buoys (de la Fontaine, 1996). Deleterious effects include complete blockage of water circulation, increased hull drag and slower speeds of vessels, sinking of buoys, as well as the fouling of beaches with sharp-edged mollusk shells. ZM propagate very efficiently, and are spread over large distances via an initial planktonic larval (veliger) stage before attachment to a suitable hard surface. There, they tend to form dense masses (druses) firmly bonded to the substrate by their strong byssal threads (Dermott and Munawar, 1993).

This reproductive mechanism, when added to the lack of local predators or any other significant ecological check on their growth, has made ZM a serious threat to commercial installations and ships on the Great Lakes. Since their inadvertent release into Lake St. Clair through dumping of ballast waters of a European vessel in 1986, ZM have expanded rapidly throughout most of the Laurentian Great Lakes and adjacent watersheds. These exotic mollusks now occur in dense colonies on the bottom of western Lake Erie where they cover virtually all the exposed hard substrates (bedrock outcrops, shipwrecks) and areas on the bottom covered by boulder- and cobble-sized material, usually found in shallow waters. More recently, extensive zebra mussel colonies are being found in deeper areas of western Lake Erie (average depth: 10 m) on soft, muddy substrates once believed to be inhospitable to them. Given the fact that they are filter-feeders, drawing in and filtering nutrients carried as suspended particles from considerable quantities of water, their expansion to such habitats might have serious implications for contaminant transfer from the water column to the bottom sediments, and also for bottom sediment resistance to erosion and resuspension. The study was aimed at quantifying the density and the distribution patterns of mussel colonization in the basin as a first step in investigating the effect on key sediment

Fig. 9. Since 1986, when they were inadvertently introduced to the Great Lakes, populations of the benthic zebra mussel (Dreissena polymorpha) have risen to as high as 300,000 individuals per square metre in the western basin of Lake Erie.centre and port.

properties of such an abrupt change in benthic community structure. By linking their distribution with substrate properties, we hope to identify key processes and controls on colonization. Some preliminary findings of this study have been published in Rasul *et al*. (1999) and in Coakley *et al*. (1997).

### *Study Methodology and Results*

Underwater video imagery and diver-collected samples taken from representative soft-sediment areas in western Lake Erie showed colonization levels of up to 25,000 live mussels per $m^2$ in soft sediments (adults with shells >10 mm comprised 20-50 %). This is lower than the densities exceeding 342,000 mussels per $m^2$ found on hard substrates (Leach, 1993). More than 170 km of digital side-scan sonar records confirmed that colonization patterns over the area were not random, but showed distinctive spatial signatures ranging from 30 m long parallel stripes, to ovate, football-shaped masses. Broad irregular mats were found in association with hard bottoms (bedrock, boulders, or wrecks and large debris). From the four representative areas, relationships were assumed between major substrate type and mussel quantities. Colonization density of each of the major bottom types was combined with digitized percentage of areal coverage for these bottom types in western Lake Erie (Rasul *et al*., 1999), producing a first-order approximation figure of $10^{14}$ individuals for the total population of mussels in the western basin. Such a large number of benthic organisms, constantly filtering the overlying water for organic matter and nutrients, is bound to have a significant impact on the lake ecology, ranging from disruption of nutrient dynamics to interference with fish-spawning conditions. These effects are only now being investigated and brought to light.

## Discussion

### *Comparisons with the Red Sea Coastal Contamination Situation*

The differences between the physical environment of the Red Sea and that of the Great Lakes are considerable and any comparison must be done with caution. Therefore, the chemical behavior and dynamics of individual aquatic contaminants is expected to be somewhat different, given the contrasting conditions of salinity, depth and temperature. Also important differences in population densities and industrial activities of bordering communities preclude any direct transfer of research insights from one area to the other. The experiences with coastal contamination observed in the tropical waters of the Bahamas (tar balls on beaches, sewage contamination of fish retention areas), however, may be related more readily to the Red Sea environment. In the discussion below, we use the experiences in the Great Lakes and the Bahamas to provide some useful lessons and cautions for managers of coastal ecosystems in the Red Sea.

### *Coastal Zone Contamination Issues for the Red Sea*

The level and type of coastal zone contamination in the Red Sea is generally quite low at present, and confined mainly to around major population centres, such as Jeddah. In northern areas such as Sinai region (Gulf of Aqaba) and the Egyptian coast (Gulf of Suez) environmental resource conflicts between the expanding tourist and reef-diving concerns and the petroleum exploitation and shipping sector are possible. For the Saudi Arabian coast, the major contaminant problem appears to be related to the disposal of industrial wastes, municipal sewage, hypersaline brines from desalination plants, and fish treatment wastes associated with the city of Jeddah (El-Rayis *et al*., 1984 and Saad & Fahmy, 1996). Refineries and oil handling facilities south of Jeddah are also cited as sources of marine pollution through the release of toxic petroleum compounds (Al-Lihaiby & Al-Ghamdy, 1997). A comprehensive discussion of the problems posed by all these environmental hazards is beyond the scope of this report; rather we will discuss those that have an affinity with studies by the authors in the western hemisphere. Because of the difficulty in obtaining references for other Red Sea areas, this report will focus primarily on the Saudi Arabian coast and on the Jeddah area in particular.

#### *Sewage-based Contaminants*

Partially treated sewage effluent treatment for the city of Jeddah is discharged directly into coastal lagoons, or into the harbour, where it is transported to the open sea by tidal action. According to El-Rayis (1998) Jeddah's two STP facilities discharge a total of more than 100,000 $m^3$-day$^{-1}$, or 37 million $m^3 \cdot y^{-1}$. The harbour (South Corniche) site has a discharge of 100,000 $m^3 \cdot day^{-1}$ of sewage and industrial waste. Depending on the level of treatment, these effluents carry significant loadings of nutrients (P, N, Si) and faecal colliform bacteria, as well as toxic trace metals and organics, to the coastal zone. This transfer of contaminants is increased greatly if the lagoons are dredged periodically.

Nevertheless, studies of contaminants in the coastal zone of the Red Sea are still at the stage of identification of impacts, and focus mainly on the water column (El-Rayis *et al*., 1984). A number of authors have cited the negative effects of sewage contamination on zooplankton, benthic foraminifera and on mangroves. No studies were found dealing with the transport or spread of contaminants to clean-water coastal amenities such as beaches, coral reefs, fishing grounds or nurseries. The only sediment-based contaminant studies noted were by Rifaat (1994).

The scarcity of sediment surveys or assessments is a major problem, especially with respect to coastal zone management and monitoring of conflicting resource uses. In the Great Lakes, bottom sediments provide a more accurate long-term assessment of contaminant dynamics in the environment than that provided by the water column or indicator organisms (Coakley and Mudroch, 1996). Systematic survey of nearshore sediments and contaminant distributions in the vicinity of sources of nearshore pollution that share the coast with clean-water amenities can provide valuable information for the design and location of municipal and industrial outfalls. The environmental problems associated with the system for disposal of sewage effluents now in place in Jeddah (smells, impacts on mangroves) might also be having an unknown cumulative impact on nearby facilities that are sensitive to sewage contamination (for instance, mariculture, fishing grounds). Tracer studies using fecal sterols or other conservative organic species could play a role in the assessment of this impact, as well as in providing a baseline for future monitoring.

### *Industrial Contaminants*

The severity of the problem of industrial discharges into the Red Sea has not been clearly defined. Contaminants from refineries and desalination plants contain a number of toxic components that can harm reef organisms and fish stocks. In the Great Lakes, tracer studies in the Humber River area of Lake Ontario have shown that the spatial distribution of sediment concentrations of trace metals and organics, if they are conservative, can be used to indicate their transport patterns clearly. Before such techniques can be feasible in the Red Sea environment, a careful evaluation of the behavior and stability of priority metal species in conditions of varying temperature, Eh, and salinity would be necessary.

As shown by the Bahamas experience, petroleum discharges into the aquatic environment is always undesirable and causes harm to sensitive ecosystems. The impacts range from surface slicks to tar balls on beaches or on the bottom in the nearshore zone. Tar balls have already been reported in the Gulf of Suez and are identified components in the coastal environment surveys of the Red Sea proposed by the World Bank Blue Team and the UNEP.

### *Invasion by Exotic Species*

As noted in the Great Lakes, alien species introduced to a new area have the potential for a population explosion that can have devastating effects on the local ecosystem. Like the zebra mussel in Canada, there are marine species from other areas that can negatively impact Red Sea aquatic life. Although no such threat appears in the current literature on the Red Sea, the impacts of species such as the "crown-of- thorns" starfish (*Acanthaster planci*) elsewhere in the Pacific region (*e.g*., the Great Barrier Reef of Australia) is cause for concern.

## Conclusion

Despite the major difference in physical environment between the Great Lakes, the Bahamas, and Saudi Arabia, there is much common ground insofar as coastal zone contaminant problems are concerned. For this reason, similar methods of studying and assessing the problems can be applied to all these areas. Research on the dispersal and mixing of sewage-related contaminants in Lake Ontario using tracers has provided a methodology for use in the design and location of sewage treatment plant outfalls. Experience from the Bahamas as well shows that these discharges can travel considerable distances to impact sensitive areas, such as beaches and mariculture. The use of fecal sterols to understand the impacts of the sewage wastes at Jeddah might provide some useful answers to these environmental problems. Other problems experienced outside the Red Sea (beach pollution by tar balls, exotic species) have not yet appeared to any great extent in the area. Nevertheless, the countries bordering the Red Sea must remain vigilant and also encourage multi-lateral protocols to ensure that petroleum discharges from ships or from shore-based operations are controlled. Also the transfer of exotic organisms through ballast water dumping of ships from the Pacific Rim, where *Acanthaster* is endemic, should be a high priority concern of all the Red Sea nations.

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# المحاور الشمولية للتلوث المتصاعد للمناطق الساحلية وتداعياتها : تطبيقات على بيئة البحر الأحمر

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*المستخلص.* تعتبر المياه الساحلية في المناطق المدارية والتحت مدارية من أهم البيئات ، من حيث إنتاجيتها وعائداتها الاستثمارية ، وكذلك الأكثر عرضة للتهديدات من التلوث الناتج من الصناعات والأنشطة الآدمية .

والتعرف على المحاور ذات الأهمية في البحر الأحمر ، يمكن أن يأتي من خلال الخبرات المكتسبة في مناطق شبيهة في أماكن مختلفة من العالم ، بما في ذلك نصف الكرة الغربي .

بشكل عام فإن أهم ما يهدد صحة البيئة الساحلية هو الامتداد العمراني ، والنشاط الصناعي ، والملاحة المكثفة ، واستغلال آبار البترول في المياه العميقة ، والتطور السياحي . وبالرغم من أن البحر الأحمر يتميز بكثافة سكانية منخفضة على سواحله ، مازالت هناك حاجة ملحة لإدارة ساحلية مناسبة . والامتداد العمراني والأنشطة الصناعية هي العوامل الرئيسية للتلوث بالعناصر بالقرب من مدينة جدة ، إضافة إلى مياه الصرف من محطات التحلية ومعامل التكرير . هذه الملوثات المرتبطة بالتوسع العمراني عادة ما تتوافق مع التلوث بمخلفات الصرف الصحي والعناصر المغذية من محطات معالجة مياه الصرف الصحي ، كلها يمكن أن تترك آثاراً سلبية على الشعاب المرجانية ، الشواطئ ، ومزارع الأسماك ، والبحار ، وكذلك على أشجار المانجروف . ويمكن أن يستخدم البحث الذي أجري في جدة أو أونتاريو بكندا ليمدنا بوسائل لدراسة انتشار هذه الملوثات عن طريق الرواسب . السفن العابرة لقناة السويس تحمل شحنات (بعضها سام أو ضار للحياة البحرية) تهدد الثروات الساحلية عن طريق الحوادث التي تؤدي إلى انتشار هذه الشحنات في الوسط . وقد أفادت البحوث التي أجريت في أماكن أخرى (جزر البهاماس) عن تواجد كرات القطران أن تأثيرها خطر وتراكمي ليس فقط على الشواطئ ، والشعاب ، والمصايد ، وإنما أيضًا على أحياء القاع .

كما أن السفن التي تعبر البحر الأحمر لها المقدرة على إدخال أنواع من الأحياء السامة من مناطق بعيدة ، والتي يمكن أن تضر بالحيوانات البحرية للبحر الأحمر ، خاصة نجم البحر *Acanthaster planc* هذه الامكانية تبرزها حالة إدخال بلح البحر الأوروبي *European zebra mussel (Dreissena)* إلى البحيرات الكبرى عام ١٩٨٦ .