metallic processing wastes from industrial operations. Data includes information on the basic physical and chemical properties, production figures (U.S. and foreign), uses, environmental leakages, routes through the environment and potential effects on the environment. The information has been indexed and is available through the Environmental Science Information Center, Marine and Earth Sciences Library (Fisheries Branch), 3300 Whitehaven Street N.W., Washington, D.C., 20235.

3rd International Biodegradation Symposium

The Biodeterioration Society is organizing the Third International Biodegradation Symposium from 17 to 23 August 1975 at the University of Rhode Island, Kingston, RI, U.S.A. The provisional programme includes symposia on the 'Metabolism of Hydrocarbons', the 'Mechanisms of Materials Degradation in the Marine Environment', the 'Biodegradation of Oil in Aquatic Environments', and sessions on 'Bioanalytical Techniques', 'Biodegradation of Synthetic Organic Compounds', 'Biodegradation of Wood', and the 'Microbiology of Hydrocarbon Degradation'.

There are quite a number of marine papers in these and the other proposed symposia and sessions.

Shell Disease in Crabs and Lobsters from New York Bight

Dumping grounds in New York Bight receive very large quantities of sewage sludge. Lobsters and rock crabs collected in or near the dumping grounds sometimes show various pathological conditions of the shell and gills. In this study the histopathology of 'shell disease', the causative agents and its effects on respiration are discussed in connexion with a possible association with the disposal of solid wastes into the ocean.

Selected areas of the New York Bight have been used as sites for the disposal of sewage sludge, contaminated dredging spoils and other wastes for over four decades. Gross (1970) reported that approximately 9.6 million tons of waste solids per year were dumped during the period 1964–1968. This dumping represents the largest source of sediments entering the North Atlantic Ocean from the North American Continent (Gross, 1970).

Until recently there was little information available as to the effects which these wastes have had on the physical environment or living marine resources of the Bight. In 1968, Sandy Hook Laboratory initiated a study to determine the effects of ocean disposal of sewage sludges, dredging spoils and waste industrial acids. During our collection of benthic grab samples in the Bight we noted a reduction in the bottom fauna relative to what would be expected in the area and, on several occasions, we collected
diseased crabs and lobsters from the areas receiving sewage sludge and dredging spoils. These findings prompted closer examination of the problem.

Materials and Methods

Occasional collections of lobsters, *Homarus americanus*, a commercially important species common to the area and taken by fishermen in close proximity to the sludge and spoil disposal grounds (Fig. 1), and rock crabs, *Cancer irroratus*, a potentially commercial species in the Bight, were made by means of an otter trawl or clam rake dredge. Specimens (approximately one hundred) were collected in areas inside the spoils grounds as well as outside the New York Bight or, at least, out of the influence of sewage sludge and dredge spoils contamination. Diseased crabs and lobster, approximately half those observed, that were occasionally found inside and near the disposal areas were brought to the laboratory for examination.

Equal numbers of crabs and lobsters, especially collected from clean areas, were also held for up to 6 weeks in eight 114 l. aerated aquaria containing clean sand or sludge and spoils bottoms, in order to determine whether the wastes initiated the disease.

Gill and other associated tissues of diseased crabs and lobsters from the experimental aquaria, and from the areas used for waste disposal, were prepared for microscopic examination by fixation in Bouin’s fluid, dehydration in ethanol or isopropanol, and embedding in paraffin. Sections were cut at 7–10 μm and stained with Delafield’s haematoxylin and eosin.

Results

Crabs and lobsters collected from the vicinity of sewage sludge and dredge spoil disposal areas most frequently showed skeletal erosions on the tips of the dactylopodites of the walking legs, on the ventral sides of the chelipeds, around areas of articulation where contaminated sediments could accumulate, and on parts of the exoskeleton that formed prolongations or spines; however, lesions were certainly not limited to these areas.

Similar erosions developed on all crustaceans held up to 6 weeks in aquaria containing sediment beds contaminated with sewage sludge or dredge spoils. These sediments were collected from the field. In early stages, the disease appeared as depressed ulcerations very similar to those described by Rosen (1967) for affected blue crabs. In later stages, severe erosions covered large areas of the shell and often parts of appendages were missing. These erosions developed within the 6 week exposure period.

A histological section of normal exoskeleton from the crab, *Cancer irroratus*, is shown in Fig. 2A. Sections of diseased exoskeleton from the same species showed that all layers of the exoskeleton were eroded by means of pitting and cracking away of the laminae (Fig. 2B), which sometimes separated as the erosion progressed laterally. Eroded edges were brown in colour. When the uncalcified layer was penetrated, the proximal portions of the cavity became filled with agglutinated blood cells (Fig. 2B). As the

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Fig. 2 *Cancer irroratus*: (A) undiseased exoskeleton; (B) diseased exoskeleton, arrow indicates agglutinated blood cells; (C) covering clot of blood cells replacing eroded exoskeleton; (D) epidermal cells, x indicates flattened cells.
area of erosion spread and the lesion widened, the exoskeleton was replaced by a compacted layer of blood cells forming a tight covering clot (Fig. 2C). The epidermal cells lost their columnar integrity and, although not necrotic, they did become either rounded or flattened (Fig. 2D).

Lobsters, *Homarus americanus*, held for up to 6 weeks in aerated aquaria containing sewage sludge also developed ulcers and shell erosions similar to shell disease. In addition, their gills became fouled with granular material, and a dark brown coating covered the filaments (Fig. 3B). The chitinous covering of the filaments often was eroded and the living underlying tissue became necrotic (Figs. 3C and 3D). The necrotic areas stained very densely with haematoxylin. Eroded filaments appeared brittle and on occasions were broken (Fig. 3C). We did not observe these phenomena in controls held for up to 6 weeks (Fig. 3A). In lobsters held on sludge the surfaces of the scaphognathites became mottled with brown crusty patches which were extremely basophilic in histological section. Advanced pathological stages showed degeneration of the epithelium and complete disruption of the internal connective tissue (Fig. 3F). Again, these conditions did not appear in lobsters held for 6 weeks over clean, uncontaminated sand or collected from clean areas.

The gills of all crabs maintained in aquaria containing sewer sludge developed a brown coating, a distorted and sometimes thickened cuticle, and accumulations of detritus between the lamellae. Ulcerations occasionally appeared on the exoskeleton. The gills of crabs held in control aquaria for up to 6 weeks remained clean (Fig. 4A). The gills of most crabs (*C. irroratus*) collected from the sewage dumping and dredge spoil disposal grounds were almost invariably more severely clogged by detritus, oily sand, and other debris than those taken from crabs held in experimental aquaria. Histological sections showed deeply stained thickenings, an apparent coating of debris along the chitinous layer and some tissue degeneration (Fig. 4B). Skeletal erosions were also common.

The general surface areas of the experimental animals held in the aquaria were covered by a fine layer of orange pigmented material. Since it resembled the thin oxidized layer that forms on the surface of sewage sludge both in the field and in aquaria, this layer may have been an oxidized form of the disposed waste products. This material could be wiped off but was not easily removed by gentle washing. This characteristic suggests that it might be a physically stable complex which would allow the incubation of microorganisms on the surface of the exoskeleton, preparing the way for external penetration of the exoskeleton.

Discussion

Whether the cause of the chitin erosion is fungal or bacterial is not known. Hess (1937) described a shell disease in *H. americanus* apparently caused by a small chitinoclastic, rod-shaped, gram-negative bacterium with lesions and ulcerations conspicuous on the exoskeleton. Sawyer & Taylor (1949) reported that the chitinous covering of the gills may be destroyed. Necrosis of either the underlying epidermis or connective tissue was not mentioned. Shell disease occurs in numerous crustaceans of several orders (Rosen, 1970; Cook & Lofton, 1973). Cook & Lofton (1973) suspect chitinoclastic bacteria to be the causative agent of shell disease in penaeid shrimp and blue crabs. Exoskeletal erosions found in crustaceans in Europe have been attributed to fungi (Mann & Heplow 1938; Gordon, 1967), although chitinoclastic bacteria are common in marine sediments (Waksman et al., 1933; Zobell & Rittenberg, 1938; Zobell, 1939; Hock, 1940, 1941) and may be found as commensals on the exoskeleton (Lear, 1963; Rosen, 1967). Sediments in the New York Bight contain large numbers of bacteria. Coliform counts with as high as 920,000 MPN/100 ml have been found (National Marine Fisheries Service, 1972). Rosen (1970) suggests that several organisms are responsible for shell disease. If so, the pathological manifestations are similar whether one or more taxa initiate the lesions. The chitin digesting organisms may not be pathogenic under ordinary circumstances, but may become so under debilitating conditions (Rosen, 1967).

Such conditions as fouling and low oxygen tensions may represent additional, possibly synergistic, stresses. The degeneration of the cuticle and chitin covering the gills and exoskeleton may expose the underlying tissues to other pathogens common in sediments contaminated by sewage sludge, chemical toxins and dredging spoils. We observed that lobsters placed on sediments contaminated with sewage sludge and dredging spoils sediments for only a few hours voided fine silts from the anterior openings of the gill chambers when moved to aquaria with clean water.

It is possible that lesions of the gills and exoskeleton may permit the entrance of other pathogens that would not normally infect crustaceans with intact integuments. For instance, the bacterium, *Pedicoccus homari*, (now *Aerococcus viridans* var. *homari*) see J. Fish. Res. Bd Can., 32, 702–705, 1975) which causes a moderate disease syndrome in rock crabs (Cornick & Stewart, 1966), has been shown to enter the lobster only through ruptures in the integument (Stewart et al., 1969).

Von Bertalanffy & Krywienczyk (1953) suggest that some crustaceans may follow the surface rule of metabolism ($M = bs^{-1}$; where $M$ is metabolism, $s$ surface or length squared, and $b$ a constant). There may be many causes for this correlation; one possible is the area of respiratory surface. In *Homarus* 97% of the oxygen uptake occurs through the gills, the remaining 3% effected through the abdominal swimmeretes (Thomas, 1954). The trichobranchiate structure of the twenty pairs of gills creates a substantial surface area. *Cancer irroratus*, with eight pairs of gills of the phyllobranchiate type, inhabits the subtidal region, and sublittoral crabs have a relatively large gill area (Gray, 1957). Since the effective respiratory surface of these decapods is decreased by either fouling or necrosis of gill tissue, it follows that oxygen withdrawal from the medium would also be decreased. If fouling and necrosis are extensive, withdrawal or ventilation may not be sufficient to meet the oxygen requirements for cellular respiration.

We have found that during the summer, water near the bottom of the sewage sludge and dredge spoil disposal areas contains lower oxygen concentrations than bottom water at some distance from these areas (Pearce, unpublished data). Samples of bottom water collected approximately 1–2 m above the sediment near the centre of the sludge disposal area in July and August 1969 contained less than 1 ppm dissolved oxygen. This approaches the lethal limit for *H.*
Fig. 3 *Homarus americanus*: (A) gill of lobster held in aquarium containing clean sand; (B) fouled gill of lobster held in aquarium containing sewage sludge; (C) broken, necrotic gill filament; (D) necrotic gill filaments; (E) undiseased scaphognathite; (F) diseased scaphognathite.

Fig. 4 *Cancer irroratus*: (A) undiseased gill; (B) diseased gill.
Phytoplankton Diversity and Chlorophyll–A in a Polluted Estuary

The quantity of phytoplankton in Newark Bay, New Jersey as indicated by chlorophyll–a content of the water, is low in the winter and early spring, and fluctuates greatly during the spring and summer. Chlorophyll–a concentrations are generally less than 20 μg/l until April. Between April and August, three phytoplankton blooms were indicated by chlorophyll–a concentrations as high as 81.4 μg/l. Net phytoplankton diversity values indicated generally eutrophic conditions; however, there was no significant correlation between diversity and chlorophyll–a concentrations. A role of nanoplanckton in blooms is indicated.

In the nineteenth Century, Newark Bay (Fig. 1) supported important crab, oyster, shad and smelt fisheries (Ingersoll, 1881; Earll, 1887). However, by 1887, there were indications that pollution was destroying the shad fisheries, as these fish had acquired a coal-oil taste (Earll, 1887). All of the commercial fisheries have now been destroyed and it appears that no significant commercial

Fig. 1 Locations of sampling sites, 1–4, in Newark Bay, New Jersey, U.S.A.

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