SEWAGE CONTAMINATION OF COASTAL BATHING WATERS IN ENGLAND AND WALES[1]

A BACTERIOLOGICAL AND EPIDEMIOLOGICAL STUDY

By the Committee* on Bathing Beach Contamination of the Public Health Laboratory Service

(With 4 Figures in the Text and an Appendix)

INTRODUCTION

During the past ten years, increasing attention has centred on the discharge of sewage into coastal waters. This practice has been widely criticized on the grounds that sewage-polluted sea water is a health hazard to bathers. Demands are consequently made for more elaborate or even for full treatment of the sewage of coastal towns so as to offset this risk. The presumption that such a risk exists has, however, not been supported by adequate bacteriological or epidemiological evidence. Both medical officers of health and public health engineers have pressed for detailed studies of the subject on which a rational policy could be based.

In 1953, the Public Health Laboratory Service set up a committee with the following terms of reference: (i) to study the contamination of coastal bathing beaches by sewage; (ii) to assess the risk to health of bathing in sewage-polluted sea water; (iii) to consider the practicability of laying down bacteriological standards for bathing beaches or of grading them according to the degree of pollution to which they are exposed.

The present paper summarizes bacteriological studies made during the past five years by members of the committee on material from more than forty popular bathing beaches around the coasts of England and Wales. In addition, epidemiological evidence relating particularly to the risks of contracting poliomyelitis or enteric fever through bathing in sewage-polluted sea water has been collected with the co-operation of medical officers of health of coastal areas and is discussed in the context of the bacteriological findings.

The work described has been mainly concerned with the following lines of investigation:

First, bacteriological surveys of sewage pollution of sea water have been made

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on a wide range of beaches, with standardized techniques and media prepared with uniform batches of crucial ingredients. The findings of these surveys provide a more satisfactory basis for the comparison of the density of pollution in different bathing waters than subjective impressions of local observers.

Secondly, an attempt has been made to analyse the effects of various factors, meteorological and other, on the amount of pollution occurring on different beaches, in the hope of throwing further light on the mechanisms responsible for the eventual disappearance of sewage organisms from polluted sea water.

Thirdly, the committee has devoted much attention to the isolation of pathogenic organisms from sea water, with particular reference to the numbers of such organisms present per unit volume of sea water. Information of this kind is useful in assessing the potential risks of bathing infection in relation to existing knowledge of the infecting dose of such pathogens required for human infection to occur.

Finally, as already mentioned, the committee has with the co-operation of medical officers of health attempted to assess the risks to health of bathing in sewage-polluted sea water.

Historical survey

A brief sketch of the literature relevant to the committee's terms of reference may serve as a background to the present report. Much of the published work in this field is of interest mainly to public health engineers or marine biologists, and cannot be discussed in detail. The literature on the bacteriological and epidemiological aspects of sewage discharge into coastal waters was reviewed by Moore (1954*a*). Greenberg (1956) and Orlob (1956) have reviewed the current state of knowledge on the factors affecting the survival of sewage organisms in sea water.

Bacteriological surveys of the contamination of coastal bathing beaches by sewage

The history of sewage discharge into the sea during the past fifty years is essentially a record of the shifting balance between progressive increase in the permanent and summer populations of seaside towns and gradual improvements in sewer outfalls and in methods of sewage treatment. The steady progress in the provision of better outfalls in British coastal areas is well shown by a study of the consecutive reviews of Nichols (1898), Warr, (1932) and King (1951). An interesting chronicle of the impact, during this period, of public opinion and the advice of public health workers on official policy in improving the Los Angeles sea outfalls is given in a State of California Department of Public Health Report (Report, 1943).

The use of bacteriological survey methods for detailed study of the pollution of bathing waters by sewage was developed mainly in the United States. An early survey, that of Winslow & Moxon (1928) on the harbour waters of New Haven, Connecticut, was done to reinforce the arguments used in convincing the New Haven authorities of the need for a sewage treatment scheme to replace the discharge of crude sewage into the harbour. The total dilution of sewage in the harbour waters was 1 in 400, but areas of greater local pollution resulted from the flow of currents and local topography. Detailed results were tabulated of the coli counts of samples collected at various sampling points, and the authors demonstrated

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the effect of wind direction and tidal movements on the degree of pollution in a given bathing area. They tentatively suggested that on health grounds the average coliform count of samples from the bathing waters concerned should be not greater than 100 per 100 ml., but no logical basis for this figure was discussed, nor is it clear how the degree of pollution of bathing waters recorded in this paper was assessesd as serious on bacteriological grounds.

The development of bacteriological sampling as a survey procedure without specific epidemiological implications is well illustrated in the report of Weston & Edwards (1939) on a survey of Boston Harbour. Large numbers of sea-water samples were examined by the coliform test and lines of equal coliform density, 'isocols', plotted on maps of the harbour to show the pattern of sewage pollution under different conditions. In more recent years, an increasing elaboration of survey techniques is recorded particularly in various reports on bathing waters situated on the west coast of the United States, notably in publications from the University of Southern California in the series of studies on the coliform bacteria discharged from the Hyperion outfall at Los Angeles (Rittenberg, 1956). Little work of this kind has been reported from countries other than the United States, but mention should be made of the series of papers by New Zealand workers on the bacteriological surveys of Auckland harbours, in which the pattern of pollution in different areas is described and the effects on pollution of winds and tidal factors analysed (Wallace & Newman, 1953*a*, *b*, 1954; Wallace, Newman & Jerrome, 1956).

Surveys of the type described are of particular interest to controlling bodies charged with the disposal of sewage or treated effluents into coastal waters from cities with very large populations, particularly where the receiving area is not favoured with suitable tidal currents to carry the polluted effluents away from the shore. The emphasis of public health workers in the United States has been along slightly different lines, namely on comparative surveys designed to grade different bathing beaches according to the degree of coliform contamination found. The American Public Health Association Joint Committee on Bathing Places (Report, 1940) recommended that state health departments should undertake surveys of this type with a view to demarcating the most polluted beaches, and that these surveys should be sufficiently extensive to permit analysis of the effects of various changing factors on the degree of pollution. Scott (1951, 1953) reported the findings of surveys on these lines along the Connecticut coast.

In the surveys discussed, the coliform test was generally used to assess contamination of bathing waters with sewage, the particular technique depending on the methods routinely used in the countries concerned for the examination of drinking waters. Quantitative surveys of the distribution of pathogenic organisms in bathing waters have not been published, although various workers (e.g. Buttiaux & Leurs, 1953; Steiniger, 1951, 1955) have reported the isolation of salmonellae from sea water.

Bacteriological surveys such as those described above, and the experimental findings of many different workers, have shown that the disappearance of sewage organisms from marine receiving waters cannot be explained solely in terms of the initial dilution of the sewage in sea water and the subsequent effects of tidal and

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other currents and of various meteorological factors. Sea water has in fact been found to have a considerable bactericidal effect on sewage organisms, the mechanism of which has not yet been adequately explained. The subject has been discussed at length in the reviews of Greenberg (1956) and Orlob (1956).

The health risks of bathing in sewage-polluted sea water

The association of enteric fever with the consumption of sewage-polluted shellfish has been recognized since the end of the last century, but the Royal Commission on Sewage Disposal (Report, 1904) expressed the opinion that no serious injury to public health was to be expected from swimming in polluted sea water, provided reasonable care was taken in choosing the sites of sewer outfalls.

The literature of the intervening years gives little support for more pessimistic assessments of the health hazards of sea bathing. An outbreak of typhoid fever at a Royal Marine Depot at Walmer in Kent in 1908 (Reece, 1909) was probably caused by bathing in a sewage-polluted swimming-pool. The pool, an indoor one, in which recruits were given formal instruction in swimming, was filled with sea water through an inflow pipe on an incoming tide, and emptied periodically. It was subject to gross pollution with sewage from two outfalls, the tidal current from which ran directly towards the pool intake. Reece noted that, when the pool was filled, the water looked like London storm water, and after 2–3 days the sediment at the bottom included a greyish black layer of offensively smelling particles. Eight of the first nine recruits affected had been attached to swimming squads at the probable time of infection, and no other likely source was discovered.

The only other records in the literature of typhoid fever occurring on more or less an epidemic scale and apparently caused by bathing were associated with an essentially similar situation on a larger scale. In both instances, namely New Haven in 1921–22 (Winslow & Moxon, 1928) and New York city in 1932 (Annotation, 1932), typhoid fever was attributed to bathing in grossly polluted harbours into which large volumes of untreated sewage were being discharged. Unfortunately, no detailed epidemiological studies were published from either place, and assessment would in any case be difficult, as the method of Vi-phage typing of typhoid strains was not then available.

Apart from a few references to sporadic paratyphoid B infection associated with sea bathing (Report, 1943; Moore, 1954*b*), the more recent literature stresses the apparent lack of any evidence that bathing in sewage-polluted sea water is likely to cause enteric fever or poliomyelitis. Steiniger (1951) isolated paratyphoid bacilli in large numbers from bathing waters from the harbour of Husum in Schleswig-Holstein, where bathing is very popular in the summer months, but he could find no evidence that such bathing caused paratyphoid fever. Thompson (1950) made an epidemiological study of 345 cases of poliomyelitis notified in Auckland, New Zealand, in 1947–49. Spot maps of the location of cases in relation to the city's polluted bathing beaches showed no excess of cases in the residential areas adjacent to these beaches. Gévaudan & Tamalet (1956) discussed the relationship between bathing and disease in the Marseilles neighbourhood of the French Mediterranean coast. Although enteric fever due to consumption of local shell-fish is common in this area, and there was therefore definite evidence of the pollution of inshore waters with enteric organisms, epidemiological investigation showed that people who merely bathed in polluted water and did not supplement the bathe by eating shell-fish very rarely contracted enteric fever. There was likewise no evidence of an association between bathing and poliomyelitis. In contrast with this lack of evidence that sewage pathogens in sea water are a significant cause of disease, these authors noted a great increase in the incidence of anaerobic infections, particularly lung abscess, and in middle ear disease, since the advent of the sport of under-water fishing.

So much for the diseases caused by pathogenic organisms known to be present in sewage. Stevenson (1953) summarized the results of three extensive field studies sponsored by the United States Public Health Service to determine what relative increase in the incidence of major or minor illness might be expected from swimming in waters of varying degrees of pollution. These surveys demonstrated that appreciably more illness occurred in swimmers than in non-swimmers, irrespective of the quality of the bathing water. 'This was expected', in Stevenson's words, 'inasmuch as water is an abnormal habitat for man regardless of its bacterial quality'. Infections of eye, ear, nose and throat represented over half of the ailments reported after swimming, and gastro-intestinal disturbances about one-fifth. A careful analysis of the survey records elicited two instances of an apparently significant correlation between illness incidence and bathing in sewage-polluted waters, but the total incidence of illness in swimmers in the episodes in question never exceeded 14 per 1000 person-days. Moreover, the two instances of an apparent association between illness and bathing history concerned inland and not coastal waters.

It may be mentioned here that a number of papers in recent years record the association of sporadic cases of paratyphoid or typhoid fever with paddling in or drinking from polluted streams, e.g. Gorman & Wolman (1939), Martin (1947), Lendon & Mackenzie (1951), Annotation (1954), Kelly, Clark & Coleman (1955) and Murdock & Lawson (1957).

On the other hand, no association between poliomyelitis and river bathing has been reported in the literature. Boyer & Tissier (1950) investigated a series of 767 cases that occurred in France over a period of 7 years with this in mind, but found no evidence that bathing in polluted rivers caused poliomyelitis.

Bacteriological standards for bathing beaches

In the introduction to its 1949 report, the American Joint Committee on Bathing Places (Report, 1949) refers to 'a growing demand that this committee or some other group of public health workers propose a rigid bacteriological or other standard, whereby bathing in certain outdoor bathing waters should be condemned from a public health standpoint'. Although the Committee argued cogently that no such absolute standard was practicable or desirable, such standards have been advocated in the United States for many years and are in operation in many areas, even though no clear basis for the standards set can be detected and the levels at which the standards have been pitched have varied considerably over the years.

Houser (1934) quoted a 1912 report of the Metropolitan Sewerage Commission of New York which expressed the view that the quality of water in New York Harbour at points suitable for bathing should conform substantially to that of drinking water. Winslow & Moxon (1928), as already mentioned, suggested that the average coliform count of bathing waters should not exceed 100 per 100 ml., but Coburn (1930) suggested a maximum permitted coliform count of 10,000 per 100 ml. and quoted a bathing area where counts were consistently higher even than this without apparently causing any ill-health in bathers. Attempts to set a standard of the order of 100 coliforms per 100 ml. were discarded eventually, as such low levels were rarely attainable, and moreover streams subject to no sewage contamination might show coliform averages of 240–1000 per 100 ml. Cox (1951) described a trend in the United States towards the adoption of a median coliform index of 2400 per 100 ml. as a bathing water standard.

The subject was recently discussed in detail in the useful paper of Garber (1956), where a number of current bathing water standards are listed. Garber wrote to the public health departments of the different states and to other control agencies asking for their present standards for natural surface waters. He found that the most difficult question to get a satisfactory answer to was 'How bacteriological standards were determined and why they were decided upon'. The most frequent reply was that there was no analytical background for the limits set other than the fact that epidemiological experience under the given standards had been satisfactory. This argument was used for standards ranging from a median coliform count of less than 2400 per 100 ml. down to a requirement that no coliform organisms should be present.

MATERIALS AND METHODS

CHOICE OF SUITABLE BATHING BEACHES

Members of the committee selected bathing beaches within easy reach of their respective laboratories for detailed bacteriological surveys. Most of those studied were subject to greater or lesser degrees of sewage pollution, but some bathing waters with virtually no sewage contamination were included for comparison. In general, an approach was made to the local authority concerned, and the committee owes grateful thanks to many medical officers of health, public health inspectors and municipal surveyors for their co-operation in the investigations that followed. Naturally, the basis of co-operation was that the beaches studied would not be mentioned by name in any publication made in due course by the committee. Code letters only, therefore, are used in this paper for the various beaches discussed.

SAMPLING

Sampling sites

A limited number of samples were collected from boats, when interest centred on the movement of sewage from outfall points or on a comparison of the course taken by floats with the results of serial bacteriological examinations. More commonly, however, a number of fixed sampling points spaced at equal intervals on one or both sides of the outfall were selected along the length of the beach under investigation. Samples were collected at different stages of the tidal cycle along lines passing through these points and at right angles to the shore line.

Analysis of the committee's results underlines the importance of choosing sampling points that lie on parts of the bathing beach actually frequented by bathers. Samples taken from points adjacent to the sewer outfall usually showed heavy pollution, but, unless these points were relatively accessible to bathers, this finding was scarcely relevant in a survey of the bathing beach in question.

Materials examined

Almost all of the committee's survey results are based on the examination of sea water. On certain heavily polluted beaches, however, samples of sand or mud were also collected and examined bacteriologically. A number of workers have suggested from time to time that sand, with its filtering and adsorptive powers, might be a useful alternative material to sea water in bacteriological surveys. Many beaches however are pebbly or shingly, and on these it may be impossible to collect samples of sand. Although, therefore, useful evidence of bacterial pollution of bathing beaches may be obtained by examination of sand, sea water must remain the basis of comparative tests of varying degrees of sewage contamination.

In certain investigations, sewer swabs were placed in the sewers proximal to the outfall point to determine the presence or absence of salmonellae in the effluent before discharge.

Collection of sea-water samples

In the Ministry of Health official memorandum on the bacteriological examination of water supplies (Report, 1956) particular stress is laid on the importance of securing a sample that is representative of the water being examined and on the care needed to avoid accidental contamination of the sample during collection. In sampling sea water the latter requirement is of relatively lesser moment, and the collection of truly representative samples almost impossible. In a polluted outfall area, sewage organisms are not all distributed homogeneously; some are sedimented on to the sea bottom, or concentrated in floating faecal particles or masses, and the act of collecting the sample may by disturbing the sea-bottom sediments disturb the bacteriological findings. Sea-water samples as examined in the laboratory, therefore, may be considered more as washings of polluted material than as fair samples of the total quantity of pollution to be assessed.

Samples of sea water were collected by wading into 1–2 ft. of water and filling suitable containers below the surface by methods essentially identical with those described for the direct sampling of reservoirs (Report, 1956). The containers used varied in capacity from 300 ml. to 3 l. according to the examination required. Wide-mouthed containers proved very much more convenient than the narrow-necked bottles generally used for the collection of drinking water samples; the relatively greater risk of accidental contamination associated with the use of such containers was not of much importance in sampling water known to contain sewage organisms in appreciable numbers. The samples were returned to the laboratory and tests put up as soon as possible after collection.

BACTERIOLOGICAL METHODS

The tests used included those serving as indicator methods for the detection of sewage contamination, and procedures for the isolation of pathogenic bacteria and viruses from sea water.

Presumptive and differential coliform tests

The coliform test formed the basis of the committee's investigations on the presence of sewage organisms in sea water, and with minor exceptions discussed below the methods used were those laid down in Ministry of Health Report no. 71 on the bacteriological examination of water supplies (Report, 1956). Certain differences of emphasis in the application of this test to sea water may be referred to at this point. The bacteriologist's concern in the examination of drinking waters is to detect evidence of minimal excretal pollution, and *Escherichia coli* I is the indicator organism the presence of which most determines the interpretation of results obtained. The presence of coliform organisms other than *Esch. coli* type I or of *Clostridium welchii* may point to more remote excretal pollution, not necessarily of human origin. With sea water from polluted bathing beaches, on the other hand, there is usually no doubt that the coliform organisms isolated from the sea-water sample are derived from sewage, and the bacteriologist is more concerned with the topographical distribution of the sewage organisms in the bathing area than with deciding whether the organisms recovered by his tests are of excretal origin or not. Again, the distinction between remote and proximal pollution is of less importance in water known to be subject to more or less continual pollution with sewage and is also more difficult to make. No attempt has been made in the present study to investigate, as have some French workers (Dienert & Guillerd, 1940), the possibility of assessing by biochemical methods how long coliform organisms isolated from sea water have been in the sea before the collection of the sample from which they have been isolated.

Apart from the differences in emphasis described above, the relatively heavier pollution of sea water than of drinking water supplies with sewage makes it practicable to examine sea water routinely for pathogenic bacteria and viruses. The isolation of such pathogens serves in turn as a check on the validity of the coliform test, as well as being a useful basis for epidemiological studies. The higher coliform counts of sewage-polluted sea water also make possible the use of plate count techniques if coliform counts of less than 100 per 100 ml. can be ignored.

Some technical aspects of the coliform tests used by the committee are discussed in the following paragraphs.

Media

MacConkey broth. For comparative surveys of pollution on different beaches, standard batches of sodium tauroglycocholate and of peptone were issued to the various laboratories concerned. Bromo-cresol purple was used as indicator instead of neutral red because of the inhibition produced by certain batches of the latter dye (Childs & Allen, 1953); the known inhibitory properties of sea water itself made this change of indicator all the more desirable. Another advantage of bromo-cresol purple was its more clear-cut colour change with alteration in pH from the alkaline to the acid side.

MacConkey agar. In early roll-tube experiments, the MacConkey agar used was the modified medium of Clegg & Sherwood (1947) as recommended for the examination of shell-fish. For plate counts, the medium was made as described in Report no. 71 of the Ministry of Health (Report, 1956).

Teepol agar (Jameson & Emberley, 1956) was tested as a possibly suitable medium for surface plate counts. After overnight incubation at 37° C., a count was made of acid-producing 'coliform' colonies. For the comparative test of this medium and MacConkey broth, the results of which are summarized in Table 1, a single batch of Teepol agar was made at one laboratory and circulated to the other collaborating laboratories so as to avoid batch variation.

Calculation of probable counts. Various combinations of volumes of sea water or of appropriate dilutions of sea water were used in MacConkey broth tests according to circumstances.

(i) To cover the range of probable counts from 200 to 180,000 per 100 ml., a 15-tube test with five tubes of each of three tenfold dilutions, viz. 0·1, 0·01 and 0·001 ml. was used. Probable counts were calculated by multiplying by 100 the corresponding entries in table IV of Report no. 71.

(ii) In preliminary surveys, a 6-tube 3-dilution test with two tubes each containing 1, 0·1 and 0·01 ml. respectively of sea water proved convenient. Probable counts were read off from the appropriate table in the paper of Hoskins (1934), which is reproduced in a modified form in the Appendix to the present communication.

(iii) For some investigations a 10-tube test with ten tubes each containing 0·1 ml. of the sample covered the range of counts required. The Appendix gives the average number of organisms, and approximate 95 % confidence limits, for 0–10 positive tubes in this test. A 10-tube test with 0·01 ml. in each tube was used occasionally for very polluted waters.

Isolation of pathogenic organisms from sea water

Salmonellae

In preliminary studies, occasional samples of heavily polluted sea water were found to yield salmonellae by enrichment culture in selenite-F medium followed by subculture to Leifson's deoxycholate agar and Wilson and Blair agar. Many more positive results were later obtained, however, by filtering larger volumes of sea water and culturing the filter pads. The technique used was as follows. A 3 l. sample of sea water was collected in a large wide mouthed sterile jar of 3 l. capacity. This was filtered through a 14 cm. 'Sterimat' filter in a Buchner funnel. A 'Sterimat' of porosity 'GS' was originally used but filtration took about an hour. Equally good results were later obtained by using a coarser filter of porosity 'FCB'. To allow a rough estimation of the numbers of salmonellae on the filter, the latter was divided into four quarters with sterile scalpels and each quarter placed in a separate tube of single-strength selenite medium. Next morning subcultures were made on to Wilson and Blair agar and deoxycholate citrate agar.

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One laboratory investigating a heavily polluted area found that simple filtration of sea water through absorbent cotton wool placed in a glass funnel gave equally good results when the cotton wool was enriched in a tetrathionate medium. A critical comparison between selenite-F and tetrathionate as enrichment media could not be made for reasons discussed below.

Other pathogenic bacteria and viruses

Staphylococcus aureus. Attempts to isolate nasopharyngeal pathogens from sea water were limited by the lack of adequate enrichment media. Broth containing 7–10 % NaCl is, however, an efficient enrichment medium for *Staph. aureus*, and attempts were made to isolate *Staph. aureus* from sea water by various combinations of filtration as used for salmonellae, and enrichment in salt broth and subculture on to solid media, which included blood agar, and a non-inhibitory MacConkey agar on which *Staph. aureus* was capable of growing. On this medium, colonies of *Staph. aureus* developed a brown colour when plates were left on the bench for 24 hr. after preliminary incubation at 37° C. overnight.

Shigellae. At one laboratory, *Sh. sonnei* was isolated from sea water by direct plating on deoxycholate citrate agar at a time when an extensive outbreak of dysentery was occurring in the community from which the contaminating sewage was derived. The lack of a suitable enrichment medium for dysentery bacilli precluded any further work on the isolation of these organisms from sea water.

Mycobacterium tuberculosis. Occasional reports have been published on the isolation of tubercle bacilli from sea water receiving sanatorium effluents (Jensen & Jensen, 1942). The numbers of such organisms present in bathing waters around the British coast must be exceedingly small. A small series of attempts to isolate *Myco. tuberculosis* by culturing centrifuged deposits of sea-water samples on Löwenstein–Jensen medium were unsuccessful.

Poliovirus. Lack of fundamental studies on appropriate concentration techniques for the isolation of poliovirus from sea water limited investigation to attempts to isolate the virus directly from sea water and from washings of sand, mud and seaweed by leaving the samples in contact with HeLa cells for an hour and subsequent culture of the cells by standard techniques.

BACTERIOLOGICAL RESULTS

General observations on the presumptive and differential coliform tests

Inhibitory effect of culture media

The known bactericidal action of sea water on sewage organisms posed an immediate technical problem. The value of MacConkey broth in the coliform test depends on its inhibitory effect on non-coliform organisms. If the vitality of coliform bacilli is already depressed by the action of sea water, may the combination of sea water and of the inhibitory constituents of MacConkey broth prevent their growth altogether when coliform tests are set up on sea-water samples? A definite answer to this question can scarcely be given until we have some method of neutralizing the antibacterial effects of sea water. Even then, however, the problem of

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resuscitating organisms of impaired vitality would remain. Heinmets, Taylor & Lehman (1954), for instance, found that suspensions of *Esch. coli* apparently sterilized by various antibacterial agents could be shown to contain viable cells when incubated with various metabolites of the tricarboxylic acid cycle. In the absence of more detailed knowledge in the present context, the committee considered that the most practical approach lay in setting up coliform tests as soon as possible after the collection of sea-water samples in the expectation that at least the coliform organisms most recently discharged from the sewer outfall were the most likely ones to grow in MacConkey broth, and that these were epidemiologically of most concern.

Two findings, however, pointed to the need for further work in this field. First, occasional samples of sea water, when diluted with equal volumes of double-strength MacConkey broth, showed no growth of coliform organisms on culture, although dilutions of 1 in 5 and upwards of the same samples in single-strength MacConkey broth showed abundant acid and gas production after overnight incubation. Secondly, surface plate counts of sea-water samples varied considerably according to the batch of MacConkey agar on which the samples were plated. It appeared, however, that coliform counts by the MacConkey broth tube test were less affected by batch variations in the inhibitory properties of bile salts than were counts on MacConkey agar. Thus, a batch of bile salts used by the Public Health Laboratory Service Water Sub-Committee (Report, 1958*c*) as a control sample of very low inhibitory powers when tested by the method of Burman (1955) gave identical results with a stock batch considered to be very much more inhibitory.

Comparison between MacConkey broth counts and coliform counts on solid media

The results given in a later section of this paper show that, on most of the beaches investigated in this study, the median coliform counts of sea-water samples examined were nearly always greater than 100 per 100 ml. and often more than 1000 per 100 ml. For waters showing this degree of contamination, a surface plate count offered many advantages over the standard 15-tube test in fluid medium, first because of its simplicity, and secondly because the presence of coliform colonies on an appropriate selective medium overcomes to a large extent the risk of false positive results in the coliform test.

An attempt was made at first to use for sea-water examinations the roll-tube technique described by Clegg & Sherwood (1947) for the examination of shell-fish, i.e. a direct faecal coli count on roll-tubes incubated at 44° C. The development of this test for the examination of shell-fish occurred in two stages. In the first, a direct 44° C. test in MacConkey broth was introduced by Dodgson (1938) in order to avoid the misleading results given at 37° C. by organisms of the aerogenes-cloacae groups that had multiplied within the shell-fish. In the second, a 44° C. count on MacConkey agar was introduced by Clegg & Sherwood (1947) to avoid the big sampling error inherent in the liquid dilution method of counting. It will be shown below that in the grading of bathing beaches the results obtained were not materially altered whether the presumptive or the faecal coli counts were used as a basis for comparison. Roll-tube methods were, however, soon discarded by the committee because the results of comparison of roll-tube counts with those obtained by MacConkey broth tube tests varied greatly from one laboratory to another. Thus, one laboratory found that 37° C. MacConkey roll-tube counts on sea-water samples were of the same order of magnitude as the 'Most Probable Number' (M.P.N.) figures of MacConkey broth tests, but the direct 44° C. roll-tube counts were only between 3 and 20 % of the mean 44° C. counts obtained by subculture from 37° C. MacConkey broth positive tubes. Two laboratories, on the other hand, reported almost identical roll-tube 44° C. counts and 44° C. MacConkey broth counts. Yet another laboratory could find little relationship of any kind between the results of the two methods, while a fifth reported that 37° C. roll-tube counts came to only 5–50 % of the M.P.N. MacConkey broth counts on different samples.

In later work, a comparison was made between the results of presumptive counts in MacConkey broth tube tests and parallel counts of acid-producing colonies on MacConkey agar. This revealed considerable batch differences in the counts obtained on MacConkey agar. A MacConkey agar prepared from stock ingredients from the Public Health Laboratory Service Central Store gave very much lower plate counts of acid-producing colonies than the corresponding M.P.N. counts in MacConkey broth. Thus, from one small series of 107 samples examined at five laboratories, thirty-five samples gave MacConkey agar counts that fell below the lower confidence limits of the corresponding tube test counts. A proprietary MacConkey agar, on the other hand, when tested in parallel with the medium just described, gave considerably higher counts. It seemed, therefore, that a solid selective medium for surface plate counts on sea-water samples should be a relatively non-inhibitory one.

Encouraging results pointing to the possibility of finding a suitable solid selective medium for surface plate counts on sea-water samples were obtained in a comparison of the results of 15-tube presumptive counts in MacConkey broth and of plate counts of acid-producing coliform colonies on Teepol agar (Jameson & Emberley, 1956). Various difficulties, both of preparation and of colony identification on this medium, were reported by a number of laboratories. Careful work on a long series of samples at one laboratory, however, had shown a close relationship between Teepol agar counts and presumptive counts in MacConkey broth. A uniform batch of Teepol agar prepared by this laboratory was circulated therefore to nine other laboratories, and a comparison made between Teepol agar counts and 15-tube presumptive coliform counts on a total series of 727 samples. The median counts obtained by both methods in surveys of the ten beaches concerned are shown in Table 1. The table shows that closely similar median counts were obtained by both methods in nine out of ten laboratories. The tenth laboratory, examining samples from beach N, reported a median presumptive count in MacConkey broth tube tests of 12,000 per 100 ml. and a median Teepol agar count of only 3000 per 100 ml. This single exception to the general finding had no obvious explanation. These results suggest that some form of surface plate count on a suitable selective medium may well be the easiest method for bacteriological surveys of bathing waters.

Further work on the development of media for this particular purpose is desirable.

Table 1. *A comparison between the median presumptive coliform counts, by a 15-tube test in MacConkey broth, and median counts of acid-producing colonies on Teepol agar, obtained in surveys of ten bathing beaches*

Beach (code letter)	No. of samples	Median presumptive count MacC. broth (per 100 ml.)	Median Teepol agar count (per 100 ml.)
E	88	3,500	3,000
V	130	500	< 1,000
O	64	1,300	1,000
S	42	1,300	1,000
A	63	2,500	1,000
K	94	3,250	3,500
T	90	450	1,000
D	29	25,000	35,000
N	28	12,000	3,000
B	99	800	1,000

Relationship between presumptive and faecal coli counts on sea-water samples

With samples from a given beach the faecal coli count at 44° C. tended to bear a fairly constant relationship to the presumptive coliform count, but gross discrepancies did occur on certain samples. The distribution of positive tubes in the presumptive and faecal counts, using a 6-tube test, found in a series of 1389 samples of sea water examined by twelve laboratories, is given in Table 2. Analysis of the committee's results shows that the ranking order of different beaches is virtually unaffected by whether the median presumptive counts or the median faecal counts are used in the comparison. Table 3 lists the median presumptive and the median faecal counts obtained in surveys of fourteen different beaches. A rank correlation coefficient for the two counts gave a value of +0·95.

Table 2. *Relationship between the numbers of positive tubes in 6-tube presumptive coliform tests on 1389 samples of sea water and the numbers positive on subculture to MacConkey broth at 44° C.*

MacC. 44° C. test (no. of positive tubes)	Presumptive test (no. of positive tubes)						
	0	1	2	3	4	5	6
0	57	33	28	12	2	—	1
1	—	49	61	45	13	5	—
2	—	—	95	77	49	17	6
3	—	—	—	80	106	37	4
4	—	—	—	—	120	94	43
5	—	—	—	—	—	85	74
6	—	—	—	—	—	—	196

The degree of pollution of different bathing beaches as measured by the coliform count

It should first be mentioned that on a number of beaches examined by the committee, and known to be free from pollution with sewage, sea-water samples yielded virtually no coliform organisms on culture.

Table 3. *Median presumptive coliform counts per* 100 *ml. and median faecal coli counts obtained in surveys of sixteen beaches*

Beach (code letter)	No. of samples	Median presumptive count	Median faecal coli count
D	348	24,000	7,000
I	51	12,000	7,000
E	88	3,500	950
C	72 (winter)	3,500	800
	144 (summer)	620	230
A	63	2,500	1,300
F	110	2,400	620
N	188	2,400	620
G	70	1,600	700
O	64	1,300	800
B	222	960	230
M	153	600	230
U	115	500	100
V	130	500	< 200
W	73	250	110
X	243	230	230
Y	137	105	105

Local topography and meteorological and other factors so influence the pattern of pollution of sea water in different bathing areas that a valid comparison between several beaches as regards relative degrees of pollution is hardly possible, although with intensive sampling any one bathing area can be efficiently surveyed and a fairly accurate description given of how sewage is distributed in its bathing waters under different weather conditions and at different seasons.

The effect of various factors on bathing water pollution is discussed in a later section. In the following tables a broad comparison is made between the average degree of pollution on a number of different beaches examined by members of the committee, although the limitations of such a comparison have already been pointed out. The median presumptive coliform counts and the 5- and 95-percentile levels found in surveys on sixteen beaches scattered round all three coasts of England and Wales are listed in Table 4. Samples from all beaches were examined by precisely similar methods and with standard batches of MacConkey broth ingredients.

A further eleven beaches in different parts of the country examined by slightly different methods gave median presumptive counts of 12,000, 1,600, 600, 500, 350, 250, 250, 200, 100, 50 and 0 per 100 ml. respectively. The 5- and 95-percentile levels for these beaches are not directly comparable with those given in Table 4, because different probability tables were used for calculating counts in the tests concerned.

The median presumptive counts of Table 4 and the eleven further counts just cited are regrouped in Table 5 according to the permanent population of the town served by the sewer outfall giving rise to the pollution of the corresponding beach. The considerable differences shown in the degree of pollution of beaches polluted by the outfalls of towns of similar size merely reflect the fact that pollution is determined, not only by the amount of sewage discharged into the sea at a given point, but by the position and the nature of the outfall point, the amount of treatment to which the sewage is subjected before discharge, and the effects of winds and tidal conditions and possibly of local differences in the antibacterial properties of sea water. Nevertheless, Table 5 gives some basis of comparison for the assessment of pollution demonstrated on other beaches not investigated in the present study.

Table 4. *Median presumptive coliform counts per* 100 *ml., and the corresponding* 5-, 95- *and* 70-*percentile levels of presumptive count, obtained by a* 15-*tube MacConkey test in surveys of seventeen beaches*

Beach (code letter)	5-percentile	Median	95-percentile	70-percentile
D	2,000	25,000	180,000+	40,000
N	1,300	12,000	180,000+	20,000
H	400	7,500	180,000+	100,000
L	500	4,500	18,000+	9,000
E	<200	3,500	90,000	8,000
K	<200	3,250	180,000+	12,000
A	<200	2,500	13,000	4,500
F	500	2,000	7,000	3,500
G	200	1,700	14,000	4,500
S	200	1,300	25,000	1,700
Z	<200	1,300	35,000	3,500
O	200	1,300	5,000	1,700
C	90	800	16,000	2,500
B	<100	800	90,000	2,500
V	<200	500	3,500	1,100
T	<200	450	17,000	1,700
R	10	40	250	80

Table 5. *Median presumptive coliform counts per* 100 *ml., obtained in surveys of twenty-five bathing beaches and classified according to the permanent populations served by the sewer outfalls concerned*

Population	No. of beaches	Median counts				
150,000–250,000	5	25,000	12,000	3,000	2,500	800
50,000–150,000	4	2,000	1,700	800	450	—
20,000–50,000	6	12,000	3,500	1,300	600	500
		250				
0–20,000	10	7,500	4,500	1,600	1,300	1,300
		350	250	200	100	40

The discussion in this section has so far centred on the comparison of median counts rather than on the range of counts obtained on any given beach. The health risks of bathing in sewage-polluted sea water and the complaints of the public about the nuisance of polluted beaches, may well, on the other hand, be related not to average counts but to days when for one reason or another the pollution of the beach concerned is unusually heavy. Particular interest attaches therefore to the columns in Table 4 giving the upper percentile levels of pollution of the various beaches cited. Inspection of the figures in this column shows that on four of the beaches investigated 5% of the samples examined contained more than 180,000 coliform organisms per 100 ml. For a more detailed comparison of the upper ranges of the frequency distributions of coliform counts on these four beaches, Fig. 1 shows the cumulative frequency diagrams of coliform counts in the four surveys concerned. It is evident from this diagram that the ranking order of heaviest pollution on the four beaches will depend on which percentile level is

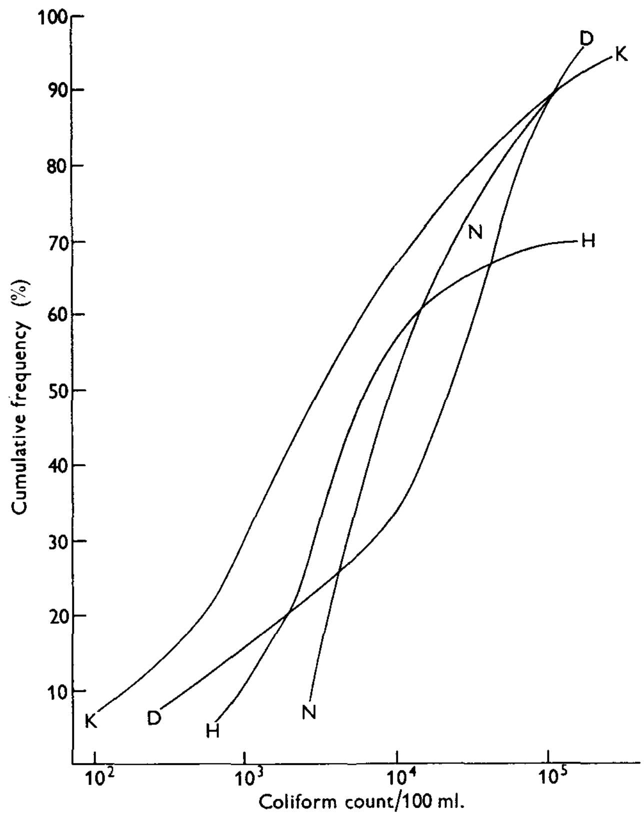

Fig. 1. Cumulative frequency diagrams of coliform counts obtained in surveys of beaches D, H, K and N.

chosen as a measure of the upper ranges of pollution. Thus, the 70-percentile level of pollution for beach H is about 100,000 per 100 ml., i.e. 30 % of the samples examined in the survey of this beach contained 100,000 or more coliform organisms per 100 ml. The 70-percentile figures for the beaches in Table 4 are given in the final column of the table.

The effect of various meteorological and other factors on the degree of pollution of bathing waters

In various reviews of the literature (e.g. Orlob, 1956) the demonstrated or postulated mechanisms whereby sewage organisms discharged into the sea eventually disappear from the outfall area are discussed at length. The effects of such factors as winds and tidal currents and of the antibacterial action of sea water on sewage organisms have often been described.

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In the surveys conducted by the present committee, details of meteorological and tidal conditions and the temperature of the sea water were recorded at the time the samples were collected or obtained later from local records. In addition, a number of experiments were done on the death-rate of coliform organisms in sea water stored in the laboratory under different conditions. A clear-cut relationship between these various factors and the degree of pollution of individual samples was by no means always evident from inspection of the results of the different laboratories engaged in this work. In the following paragraphs, the relationships between bathing water pollution and certain other factors that emerged from an examination of the results of various laboratories are therefore selected from a mass of other negative findings and are not generally applicable to all the bathing waters studied by the committee. Before these findings are discussed in detail, however, it should be pointed out that the description of a given degree of pollution on a certain beach, e.g. in terms of a median coliform count, presupposes that the limits of the beach in question are clearly defined. Thus, at one beach examined by the committee, it so happened that a stream separated the main very popular beach from another stretch of beach on which sewage from the outfall impinges. The median coliform count obtained in a survey of 243 samples from the main beach was only 230 per 100 ml., whereas the median count in a series of ninety-eight samples from the polluted stretch of beach was 20,000 per 100 ml.—a range that spans the greater part of Table 4. On this beach, therefore, the presence of a stream at a particular point has greatly upgraded the status of the beach in question, and a median level of pollution of the beach at this resort can be usefully quoted only if the precise stretch of beach is clearly defined.

Effect of tidal state on pollution

Not surprisingly, the state of the tidal cycle at which samples are collected may greatly affect the results obtained in the coliform test. Thus, on beach Q, pollution was very much greater in samples collected between three-quarter-flood and high tide. On beach P, on the other hand, pollution was greatest at low tide to half-flood. The differences depend on local topography and on the site and length of the outfall.

Effect of wind force on pollution

On exposed coasts an onshore wind may be expected to drive sewage on to the beaches, and the gross pollution sometimes seen after heavy gales is a matter of common observation. Some laboratories were able to demonstrate a close relationship between the force of onshore winds and the coliform counts obtained on sea-water samples. The most notable instance of this is shown in Fig. 2. This diagram plots on the same time-scale the mean coliform counts obtained on samples from four sampling points on a certain south-coast beach, and also the wind force measured on the Beaufort scale on the days concerned. The parallelism of the two graphs needs no elaboration.

Effect of rainfall on pollution

Analysis of the results of bacteriological survey of a certain beach during the summer of 1958 showed a number of peaks of pollution apparently unrelated to tidal state or wind force. Closer inspection of the results from individual samplin points showed that this heavy pollution occurred in the vicinity of four storm water overflows, and, when this clue was followed up, peaks of heavy rainfa followed after 24–72 hr. by the increased sea-water pollution were found to hav occurred at the relevant times. A clearer demonstration of this phenomenon ha

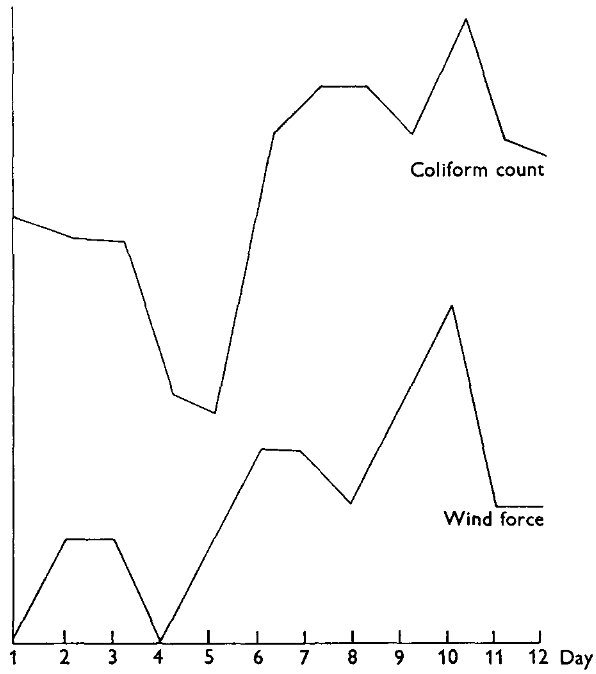

Fig. 2. Diagram illustrating increase in coliform counts of samples from beach B with increase in strength of onshore winds, during a 12-day period.

frequently been noted at certain resorts, where sewage is comminuted befo discharge during the summer months; in periods of heavy rainfall part of tl sewage by-passes the comminutor and is discharged through storm water overflov and contaminates the beaches.

Seasonal differences in pollution

A valuable series of all-the-year-round studies conducted by one laboratory c a certain beach, during the years 1954–8 inclusive, showed a consistent fall in tl proportion of samples with high coliform counts in the spring and summer month with a succeeding increase in the proportion of polluted samples as autumn ar winter approached. The seasonal changes are well shown in Fig. 3. This figu also shows the similar trend of salmonella isolations, apart from two discrepa periods in 1956 and 1958 respectively. The salmonella findings are discussed a later section.

A true seasonal difference in the death-rate of coliform organisms in the sea m obviously be masked by population changes leading to greater or less loading the sewerage system concerned. Thus, at one seaside resort, the population

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estimated to increase sixfold during July and August. Two consecutive surveys of sea-water counts were done at this resort, one during May and June, and the second during July and August. The median coliform count of 120 samples examined in the first survey was 200 per 100 ml., and the corresponding count for the second survey was 1600 per 100 ml., a difference apparently due to the population change.

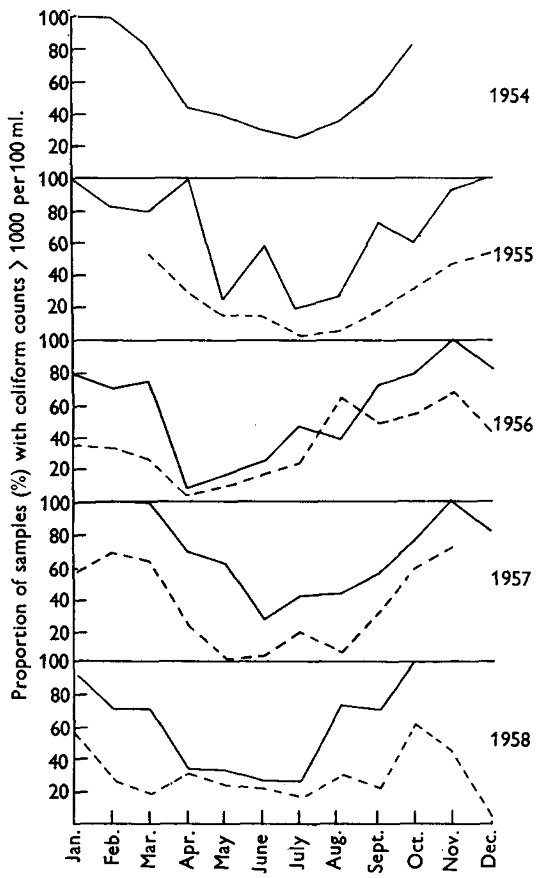

Fig. 3. Diagram showing fall in coliform counts and in salmonella isolations during 5 successive summers at beach C. Coliform counts, ———; salmonella isolations, – – – –.

The seasonal differences in pollution illustrated in Fig. 3 are similar to those recently reported by Lafontaine, De Maeyer-Cleempoel & Bouquiaux (1956) in bathing waters along the Belgian coast. One possible explanation of this phenomenon is an increased antibacterial power of sea water in the summer months, as reported by Vaccaro, Briggs, Carey & Ketchum (1950). It is interesting to note therefore that the laboratory at which the results shown in Fig. 3 were obtained found a broadly inverse relationship between coliform counts and counts of marine bacteria in a parallel series of tests, as had previously been reported by the American workers. These results might also be explained by changes in the stratification of sewage in the sea at different times of year due to altered temperature gradients (see Garber, 1956).

Effect of sea-water temperature on pollution

A finding which one is tempted to relate to that described in the previous section was noted by one laboratory on analysis of the results of a bacteriological survey of a beach situated on an almost land-locked estuary. There was an apparently clear-cut inverse relationship between sea-water temperature and coliform counts on samples from a fixed sampling point, over periods measured in days rather than months. This finding is illustrated in Fig. 4.

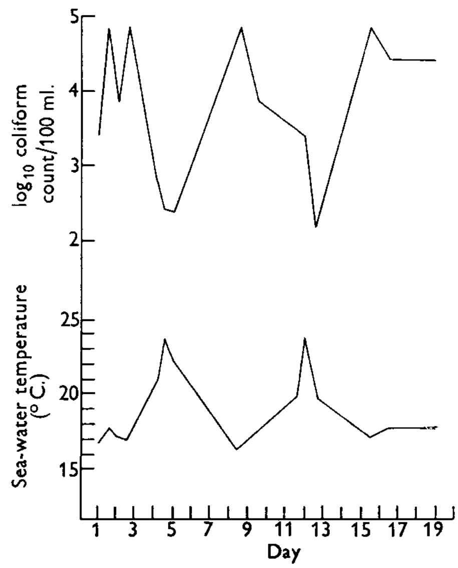

Fig. 4. Diagram showing inverse relationship between coliform counts and sea-water temperature during a 19-day period at beach D.

The death-rate of coliform organisms in stored sea water

In a number of experiments on the death-rate of coliform organisms in sea water stored in the laboratory under various temperature conditions in the dark, similar results were obtained to those previously described by other workers (see Orlob, 1956). In experiments in which the range of counts was covered by the coliform test used, a logarithmic die-away curve was found in accordance with Chick's (1908) findings on the disinfectant action of phenol. Values of the disinfection constant, k, at ambient laboratory temperatures, ranged between 0·4 and 1·3, and the corresponding times required for a 90 % mortality of the initial coliform population between less than 1 and 3 days. In parallel experiments in the same laboratory, increase in holding temperature increased the rate of bacterial die-away.

Such *in vitro* experiments are of only limited value, as marine conditions cannot be accurately simulated in the laboratory. They may give some indication, however, of the death-rate of sewage organisms in the sea.

The isolation of pathogenic organisms from sea water

The isolation of pathogenic organisms from sewage is largely conditioned by the availability of suitable technical methods for the purpose. Of the bacterial pathogens associated with intestinal disease, only the salmonella group can be said to be adequately covered by suitable techniques of direct plating and enrichment. It is not surprising, therefore, that far more information on the presence of these organisms in sea water has been obtained by the committee than on the distribution of any other pathogen. A few comments on the isolation of other organisms are made at the end of this section.

Isolation of salmonellae from sea water

Preliminary results on the isolation of salmonellae from sea water made it clear that the chances of successful isolation increased greatly with the volume of sea water examined. The technique of filtering 3 l. volumes through 'Sterimat' filters and culturing the filter pad in selenite broth has already been described.

Table 6 lists the different species of salmonellae isolated from sea water and the number of isolations of each species recorded. The large preponderance of isolations of *Salmonella paratyphi* B greatly exaggerates the importance of this organism in the present context, as the same laboratories continued to isolate it in long series of consecutive examinations of samples from the same beaches. It would seem, nevertheless, that paratyphoid bacilli were either present in larger numbers than other salmonellae in the bathing waters examined or were more readily isolated by the technical methods used, which were devised originally largely for the isolation of organisms of the enteric group.

Table 6. *Classification of a series of* 569 *Salmonella strains isolated from sea water*

	No. of isolations		No. of isolations
Salm. paratyphi B	254	*Salm. kaneshie*	2
Salm. typhimurium	80	*Salm. newport*	2
Salm. heidelberg	63	*Salm. schwarzengrund*	2
Salm. bredeney	45	*Salm. tennessee*	2
Salm. oranienburg	42	*Salm. aba*	1
Salm. stanley	17	*Salm. binza*	1
Salm. derby	9	*Salm. durham*	1
Salm. bovis-morbificans	6	*Salm. infantis*	1
Salm. worthington	6	*Salm. irumu*	1
Salm. enteritidis	6	*Salm. kentucky*	1
Salm. typhi	5	*Salm. lexington*	1
Salm. senftenberg	4	*Salm. menston*	1
Salm. idikan	3	*Salm. montevideo*	1
Salm. richmond	3	*Salm. taksony*	1
Salm. anatum	2	*Salm. thompson*	1
Salm. butantan	2	*Salm. waycross*	1
Salm. cubana	2	Total	569

The relationship between salmonella isolations and the coliform counts of the samples that yielded salmonellae by filtration and enrichment is summarized in Table 7, which shows the proportion of samples with coliform counts falling within various ranges that yielded salmonellae on culture. This table is based on the examination of a series of 859 samples in five laboratories, and shows a progressive increase in salmonella isolations with increase in coliform counts. Of the

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twenty-two samples with coliform counts in the range 0–1000 per 100 ml. that yielded salmonellae from 3 l. samples, one sample was salmonella-positive although the coliform count was 0 per 100 ml., six had counts of 250–350 per 100 ml. and fifteen had coliform counts of 500–950 per 100 ml.

The majority of samples yielding a salmonella on culture did so only from one of the four quarters into which the filter pad was divided before enrichment. This suggested that in most samples very few salmonellae were present in the 3 l. volumes examined.

Table 7. *A comparison between the presumptive coliform counts per* 100 *ml. on* 859 *samples of sea-water and the isolation of salmonellae from them*

Presumptive coliform count/100 ml.	No. of samples	No. positive for salmonellae (percentage in brackets)
0–1,000	165	22 (13·3)
1,000–10,000	353	104 (29·1)
10,000+	341	137 (40·1)

Miscellaneous findings of different laboratories on the isolation of salmonellae from sea water and sand

The following paragraphs give some further details of various findings of a number of laboratories that made intensive studies on the isolation of salmonellae from sea water.

Laboratory X, as already mentioned in a previous section, made all-the-year-round surveys of coliform counts during 1954–58 and parallel attempts were made to isolate salmonellae from 3 l. volumes of sea water. Fig. 3 shows that the fall in coliform counts during the spring and summer months was paralleled by a fall in salmonella isolations. Inspection of the graphs suggests a departure from this close relationship on only two occasions, viz. in August 1956 and from October to December 1958.

Higher salmonella isolation rates in relation to the coliform counts were obtained by this laboratory than by any other laboratory examining an adequate series of samples. Thus, 77 (42·3 %) out of 182 samples with coliform counts of 1000–10,000 per 100 ml. were salmonella positive, and 20 (80 %) out of 25 with coliform counts of 10,000 to over 18,000 per 100 ml.

Laboratory Y studied the distribution of salmonellae in the sea water and the sand of the beach giving the highest median count of those listed in Table 4. Considerable difficulty was at first experienced in isolating salmonellae from heavily polluted samples; this was overcome, to some extent, by filtering 1 l. instead of 3 l. volumes at a time. Still later, a method was devised of filtering 3 l. samples through a filter pad, culturing each quarter pad in enrichment medium for 24 hr., diluting each culture to 1 in 10 and 1 in 100 and plating these dilutions after further incubation. This method greatly increased the frequency of salmonella isolations. An attempt to apply the method to a comparison of the efficiency of selenite and tetrathionate enrichment media failed, however, for the curious eason that different serotypes of salmonella were isolated from the various ractions enriched in the different media.

Laboratory Z. A series of 401 samples of sea water from beach H was examined n 1957 by the coliform test and for the presence of salmonellae. The technique liffered from that used by most other laboratories, in that 450 ml. volumes of sea vater were filtered through absorbent cotton wool, which was then enriched in etrathionate medium instead of selenite broth. (Later experiments by this aboratory suggested that filtration of a 3 l. sample would have approximately loubled the number of salmonella-positive samples). In the present series of nvestigations, 131 out of 401 samples gave presumptive coliform counts of less han 100 per 100 ml. and of these 12 (9·1 %) contained salmonellae. Of 270 samples vith coliform counts of more than 1000 per 100 ml., the number of salmonella-ositive samples was 103 (38·1 %). In a later survey of an adjacent estuary the ame laboratory examined 191 samples by similar methods. All samples in this eries had presumptive coliform counts of over 1000 per 100 ml.; sixty-two 32·4 %) were salmonella-positive. Of sixty-seven samples with coliform counts f 1000 to 10,000 per 100 ml., eleven (16·4 %) were positive for salmonellae. The 124 samples with coliform counts of 10,000–25,000+ per 100 ml. yielded fifty-one 41·1 %) positives.

The optimal time of subculture of tetrathionate enrichment cultures so as to btain the highest score of salmonella-positive specimens was investigated by this aboratory in some detail. In a group of ninety-five salmonella-positive samples rom the two surveys mentioned above, the results of tetrathionate subculture fter 1, 2, 3 and 4 days' incubation were compared. The number of new isolations n each of these 4 days were respectively 60, 21, 4 and 10. Thus, subculture after . and 2 days' incubation only would have yielded eighty-one out of ninety-five ositives.

Isolation of other pathogenic organisms from sea water

The following brief sections on the isolation of *Staph. aureus* and of poliovirus rom sea water record essentially negative findings.

Staph. aureus. As already mentioned, some attempts were made to isolate *Staph. aureus* from sea water, this being the only nasopharyngeal organism for the solation of which adequate enrichment media are available. One laboratory eported that seven out of 217 samples of sea water yielded, from 3 ml. volumes nriched in salt broth, brown colonies on MacConkey agar which gave a positive lide coagulase test and were presumptively identified as *Staph. aureus*. No *Staph. aureus* was isolated, however, from a series of 1–3 l. volume samples, 125 in all, xamined by the salt broth enrichment method in six laboratories, and it would eem that the numbers of *Staph. aureus* present in sewage-polluted sea water must e very small.

Two laboratories reported that salt-resistant Gram-negative rods present in ewage-polluted sea water and capable of multiplication in 7·5 % salt broth made he latter medium relatively ineffective in isolating staphylococci from sea water. By using a tellurite broth enrichment instead of salt broth, with subculture to salt agar, another laboratory isolated *Staph. aureus* from two out of fifteen 3 l. samples of sea water—not included in the totals given above—and this technique deserves further study.

Poliovirus. A series of seventy-nine samples which included forty-eight of sea water and in addition samples of river water, mud, seaweed and shell-fish were collected from an area where sewage is discharged into the sea and examined for poliovirus with negative results. As mentioned above, no concentration techniques were used, and it is probable that because of the large dilution factors involved, the isolation of poliovirus from sea water is not likely to be successful without such methods.

EPIDEMIOLOGICAL INVESTIGATIONS

The almost total lack of evidence of any significant health risk attached to sea bathing has already been pointed out. The committee was particularly anxious to assess the risk of contracting enteric fever or poliomyelitis through bathing in sewage-polluted sea water. Two possible approaches to the problem were envisaged. One was to conduct large-scale epidemiological field studies of the type sponsored by the United States Public Health Service (Stevenson, 1953). Apart from staffing difficulties, such studies were precluded by two main factors. First, a very high proportion of seaside bathers in the summer months are visitors and not permanent residents. This not only means that, if such bathers contract enteric fever or poliomyelitis while at the seaside, they may well have returned to their inland homes before the disease is diagnosed; it also postulates that the essential healthy controls whose bathing histories are required for the assessment of the significance of bathing in the patients must also be summer visitors to the seaside. The planning of suitable prospective surveys under these circumstances raises obvious difficulties. The second difficulty about large-scale epidemiological inquiries of this type was a conclusive one. This was the impossibly large population that would have to be studied to ensure a sufficient number of cases of enteric fever or poliomyelitis during the period of study to permit correlations with bathing histories. In discussing one of the American studies, in which records of 7520 persons were collected over a bathing season, Smith & Woolsey (1952) queried 'whether the present type of experiment, on the present scale, will ever be adequate to measure the effect upon health of swimming in waters of different bacterial quality where other than pronounced differences occur. Larger experiments of this type might be expensive or otherwise infeasible, but one of the present size and type may not produce the frequencies required for adequate analysis in the marginal water quality areas'. One need only add that these American studies covered all minor infections, and were not limited to relatively infrequent diseases like enteric fever or poliomyelitis.

The only alternative approach seemed the retrospective one, based on a study of notified cases of enteric fever and poliomyelitis. The two diseases are considered separately in the following sections.

Enteric fever

In 1957, the corrected notifications of typhoid and paratyphoid fever for England and Wales totalled 435, including 125 typhoid and 310 paratyphoid cases (Report, 1958*b*). Allowing for the large proportion of the population that does not bathe in coastal waters and for the cases explained by contact with chronic carriers or by food-borne infection, it is clear that only a small residuum of cases could possibly have been caused by sea bathing, and that a statistical study of the bathing histories of such patients and of suitable controls would necessarily take several years before significant results were likely to emerge. Incidentally, the Ministry's annual report for 1957, from which the figures given above were taken, mentions two cases of paratyphoid fever during the year in question that were ascribed to sea bathing.

As a preliminary exercise in establishing contact with the medical officers of health of coastal areas, Dr W. S. Parker collected on behalf of the committee details of enteric fever notifications during the previous 5 years from some eighty local authority districts, through the kindness of the medical officers of health concerned. The total figures recorded gave no indication, in relation to the total populations concerned, that enteric fever was unusually common in seaside residents. Moreover, a surprisingly small proportion of the cases were in the age groups most likely to indulge in sea bathing. No further study along these lines seemed worth while.

A special effort has been made during the past 5 years to maintain careful scrutiny of enteric fever cases with a view to picking out those giving a history suggesting a sea-bathing infection. Several lines of information have contributed to this study: first, the efforts of medical officers of health of coastal areas and also of the directors of coastal Public Health Laboratory Service laboratories, many of whom were members of the committee. In addition, Dr E. S. Anderson, director of the Central Enteric Reference Laboratory and Bureau, kindly added to the inquiry form sent out by the Bureau on all notified cases of enteric fever a question on relevant bathing history, and has brought to the notice of the committee all enteric fever cases giving a history of bathing in coastal waters where enteric organisms of the same phage type as those infecting the patient concerned had been isolated from sea-water samples. Apart from case-histories obtained by these channels, the members of the committee had personal knowledge of, or were given information by interested medical officers of health on, a few other cases of enteric fever in which an association with contaminated sea water seemed probable.

Relevant details on these enteric fever patients may be summarized as follows:

(i) Four cases of paratyphoid fever notified during the 3 years 1956–58 inclusive gave a history suggesting infection through bathing or playing on polluted beaches. Fortunately from the standpoint of the committee's investigations, all four were associated with beaches that had already been intensively studied by members of the committee. It is interesting and hardly a mere coincidence that the two beaches concerned were beaches D and J in Table 3 above, i.e. beaches with the highest median presumptive coliform counts recorded in the table. Further details on the patients concerned are given below.

The patient who was probably infected through bathing on beach D was a boy of 17. The beach concerned is a notoriously unsatisfactory one which at one time had prominent warning notices to dissuade bathers. *Salm. paratyphi* B phage type Taunton was isolated from a sample of faeces from this boy, received at the laboratory on 2 August 1956. He had bathed on the beach in question some time in July, and paratyphoid bacilli of the same phage type had been isolated from sea-water samples from this beach in June 1956. The patient said it was exceptional for him to bathe on beach D; he usually went to another coastal town or used the local swimming bath. No other members of his family had bathed and none developed clinical symptoms. The boy was the first type Taunton infection to be diagnosed in the town concerned in 1956. In September 1956 a case occurred in a baby who was found to have been infected by its father. In December 1956 a nurse who had suffered from vague ill-health for some months was found to be excreting *Salm. paratyphi* B type Taunton, and it transpired that she had nursed the bather above described.

Three cases of paratyphoid fever occurred in girls aged 3, 4½ and 6 years respectively who had bathed on beach J. One of these children gave an unusual history. The child attended a clinic for poliomyelitis inoculation in June 1958. The mother remarked that the child had had a brisk attack of diarrhoea on the previous afternoon and had a temperature. A sample of faeces taken at the clinic yielded paratyphoid B bacilli of phage type 1. Four home contacts and eighteen other contacts were negative. Ten days before the onset of illness the family had visited beach J and spent the day on the beach. The patient was found playing with a used sanitary towel on the beach during the day. *Salm. paratyphi* B of the same phage type as that infecting this patient had been isolated from sea water and sand on this beach on many occasions.

(ii) Two cases of typhoid fever occurred in 1950 and 1952, in male patients, who had swallowed considerable amounts of sea water 10 and 11 days respectively before-hand.

(iii) Four other cases of paratyphoid fever notified since 1946 gave a history suggesting possible sea-bathing infection, but the evidence was not clear-cut for one reason or another.

Poliomyelitis

Inquiry into the occurrence of typhoid or paratyphoid fever due to sea bathing is logical in the light of our extensive background of knowledge on water-borne enteric fever. With poliomyelitis, on the other hand, considerable uncertainty as to the mode of infection still prevails. The incidence of poliomyelitis in England and Wales during the past few years has, however, been high enough to permit a statistical study of the bathing histories of children with poliomyelitis and of a suitable control group. The study was organized for the committee, and the results analysed, by Dr W. Chas. Cockburn, director of the Public Health Laboratory Service Epidemiological Research Laboratory, and Dr W. S. Parker.

Medical officers of health of administrative areas bordering on the sea were invited to collaborate in the inquiry, and were asked to obtain a record of bathing history for 3 weeks before the onset of illness from all patients aged 0–15 years with poliomyelitis or from their parents, and to send in the completed records. The study was restricted to residents of the areas and did not include visitors. Medical officers of health were asked at the same time to choose from the birth or school registers as a control for each patient the name of a child not living in the same household as the patient, who was of the same sex, was as nearly as possible of the same age, and who lived preferably in the same street, or failing this in the same administrative ward or area. They were asked to obtain from this control child or its parents the bathing history during the 3 weeks before the onset of illness in the patient, and to include it on the patient's record card.

The study in 1957 was in the nature of a pilot trial. Fifty-six completed record cards were received for that year. Four were rejected—two because there was no history for the control children, one because the control child was 2 years older than the patient and one because the control child was the brother of the patient. The fifty-two satisfactory records were included in the analysis.

In 1958 the medical officers of health of eighty-eight coastal areas were invited to take part. It was possible to check the number of records received from these eighty-eight areas with the numbers of cases at different ages which were notified in a different inquiry. Altogether 148 cases in children 0–15 years of age were notified and records were sent in for 109 of them. Of the thirty-nine cases not included in the bathing history inquiry, twenty-seven were in one area in which an epidemic of thirty cases occurred; through pressure of work, only three record cards were completed early in the epidemic. Four cases for which record cards were not received were in another area where thirteen cases occurred, but from which records for only nine cases were submitted. Six of the rest were in areas in which only single cases were notified during the year. One was in an area where eight cases occurred but only seven were reported, one in an area where three occurred and two were reported. Except for the area with the epidemic and some of the areas where only single cases occurred, reporting was on the whole good throughout the study.

Eleven of the 109 records were excluded from the final analysis. These were the three from the area where the epidemic occurred, because there was no certainty that the three reported cases were representative; five because there was no information about the control child; one because the information for both case and control was defective and two because the diagnosis was changed. Records of 98 cases and controls reported in 1958 were included in the analysis along with the records of the fifty-two cases and controls reported in 1957, making a total of 150 cases and controls in all.

The comparability of patients and controls on the record cards submitted was scrutinized. Of the 150 control children, 112 (75 %) were born in the same month or 1 month before or 1 month after the corresponding patients. Of the remaining thirty-eight controls, twenty-three were 2–7 months older than the corresponding patients and fifteen were 2–7 months younger. The occupations of the parents of patients and controls had been recorded, and from this it was possible to classify the parents by social class as defined by the Registrar-General (Table 8).

Table 8. *Survey of bathing and poliomyelitis* 1957–8. *Social class distribution of the parents of* 150 *patients and controls*

	Social class			
	I, II	III	IV, V	Insufficient information
Paralytic cases				
Patients	11	61	17	5
Controls	15	59	13	7
Non-paralytic cases				
Patients	10	41	4	1
Controls	6	42	5	3
All cases				
Patients	21	102	21	6
Controls	21	101	18	10

In each group the distribution between social classes was similar. The patients and controls were therefore well matched for age and social class. The method of picking the control children ensured identity of sex distribution in the two groups.

The bathing history of patients and their matched controls for the 3 weeks before the onset of illness in the patients is given in Table 9, where the histories are tabulated separately for paralytic and non-paralytic patients and their controls, and according to the time of year when the case occurred.

Table 9. *Survey of bathing and poliomyelitis* 1957–8. *History of bathing at any time within* 3 *weeks before the onset of symptoms in the patients, grouped by quarters of the year*

	Patients			Controls		
Quarter	Bathed	Did not bathe	Total	Bathed	Did not bathe	Total
		Paralytic group				
2nd	3	2	5	3	2	5
3rd	19	39	58	20	38	58
4th	1	30	31	1	30	31
All quarters	23	71	94	24	70	94
		Non-paralytic group				
2nd	—	2	2	1	1	2
3rd	21	22	43	18	25	43
4th	1	10	11	1	10	11
All quarters	22	34	56	20	36	56
		Both groups				
2nd	3	4	7	4	3	7
3rd	40	61	101	38	63	101
4th	2	40	42	2	40	42
All quarters	45	105	150	44	106	150

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It will be seen that the bathing histories of patients and controls were closely similar, e.g. forty-five out of 150 poliomyelitis patients and forty-four of the corresponding 150 controls had bathed during the 3 weeks before the onset of symptoms in the patients.

Table 10 analyses the history of bathing at different intervals during the 3-week period. An entry was made in each interval in which a patient or control child bathed, but no matter how often the patient or control child bathed within an interval only one entry was made for that interval. Again, the bathing history of patients and controls was similar for the different intervals. These results strongly suggest that for patients suffering from poliomyelitis a history of having bathed during the 3 weeks preceding the onset of symptoms is probably irrelevant as a causal factor.

Table 10. *Survey of bathing and poliomyelitis* 1957–8. *Periods in the* 3 *weeks before the onset of symptoms in the patients during which the patients and controls bathed*

		Period (days)				
		1–3	4–7	8–14	15–21	1–21
Paralytic group	Patients (23)	7	6	14	13	40
	Controls (24)	12	11	13	11	47
Non-paralytic group	Patients (22)	14	14	12	11	51
	Controls (20)	6	10	11	17	44
Both groups	Patients (45)	21	20	26	24	91
	Controls (44)	18	21	24	28	91

DISCUSSION

The coliform test

A detailed discussion of the technical methods used for the coliform test on sea-water samples in this investigation is scarcely called for. Various comments in the text of the relevant sections will have shown that the committee is not prepared to dogmatize on the best methods until further work has been done in this field. By ensuring, however, that identical batches of ingredients were used in media prepared by the different laboratories and that samples were examined by closely similar techniques, the findings of surveys done on different beaches should at least be comparable to the extent that the assessment of the degree of pollution on different beaches would not have been greatly different if all the surveys had been done by one laboratory.

The relationship between presumptive coliform counts and faecal coli counts on sea-water samples examined by the committee has been discussed, and Tables 2 and 3 have been compiled to show that either the presumptive or the faecal coli average count can be used for the grading of bathing beaches. Strictly speaking, the use of these tests should have been prefaced by an extensive ecological study of the distribution of different types of coliform strain met with in sea-water, in the same way that coliform organisms found in drinking waters have been examined.

Each laboratory, however, did examine fairly large numbers of different colony types of coliform organism from MacConkey agar or Teepol agar plates of sea-water samples, and these were in general similar to those found in fresh water and when typed fell into one of the recognized categories. Moreover, coliform counts paralleled closely in general the results of sanitary surveys of the bathing areas concerned, and there seemed little doubt that at least in sea-water samples from bathing beaches not adjacent to large rivers or estuaries the coliform organisms isolated and in particular the faecal coli strains giving a positive 44° C. test were derived from the sewage effluents known to be contaminating the beaches concerned. The best evidence, however, of the validity of the coliform test for the examination of the sea-water samples studied is probably that provided by Table 7, which shows the close relationship between coliform counts and the isolation of sewage pathogens from sea-water samples.

It should perhaps be pointed out that the coliform test as here described on sea-water samples is essentially different in character from that used for the routine control of drinking waters. For sea-water samples the test is part of a survey procedure to be undertaken after careful planning, e.g. in relation to the choice of a new outfall point, and not a test for routine use like those used for drinking waters or for the routine supervision of milk or ice-cream production. The demonstration that a given sample of sea-water contains faecal coli is not particularly enlightening when the sample is one which has been collected in a bathing area known to be contaminated with sewage, and the count obtained can certainly not be validly compared with those used in the classification of piped drinking water supplies.

The results given in this paper, like those of other workers, underline again the complexity of the pattern of coliform contamination in coastal waters receiving sewage. This is not very surprising. Sewage enters the sea at an outfall point and is disseminated thence by various mechanisms which include tidal currents, winds and sedimentation on to the sea bottom. The pattern of contamination in a bathing area is a constantly changing one, not only with the changes in the different factors mentioned, but with the continual arrival of fresh material which in turn becomes diluted with more remotely contaminated sea water. It has often been shown that the numbers of coliform organisms found in sea water are fewer than would be expected on a basis of dilution alone, and much inconclusive work has been done on the mechanisms whereby this rapid death of sewage organisms occurs in sea water. The committee has not studied this phenomenon in detail, but has confirmed the fairly rapid death of coliform organisms in stored sea water, obtaining disinfection constants similar to those described in the American literature and finding that the death-rate of organisms in stored sea water increases with increase in ambient temperature.

The isolation of salmonellae from sea water

Table 7 shows that 263 (30·4 %) out of 859 samples of sea water yielded a salmonella by the filtration method described, i.e. contained a sufficient number of salmonellae in volumes of 1–3 l. to be detectable after enrichment culture of the filters through which the samples of sea water had been passed. The proportion of positive samples increased from 13·3% in sea-water samples with less than 1000 coliform organisms per 100 ml. to 40·1% in those with over 10,000 per 100 ml.

As already mentioned, the numbers of strains of the main serotypes listed in Table 6 are greatly weighted by repeated isolations of the same types from serial samples collected on the same beaches. Thus, of the sixty-three *Salm. heidelberg* isolations recorded, forty-two came from samples from one beach, eighteen from an estuary, one from a third beach and two from a fourth. Salmonella isolations were reported by nine laboratories in all; the numbers of laboratories (in brackets) where the most frequently isolated salmonellae in Table 6 were cultured from one or more samples of sea water were as follows: *Salm. paratyphi* B (8), *Salm. typhimurium* (7), *Salm. heidelberg* (4), *Salm. oranienburg* (2), *Salm. bredeney* (1). Differential viability of different salmonella serotypes in sea water has not been demonstrated, and it seems reasonable to suppose that the salmonellae isolated in the present investigation were those present in largest numbers in the bathing waters studied. The paratyphoid bacilli were presumably derived largely from carriers; among those phage typed, a wide range of types known to be associated with paratyphoid fever in this country were identified, including types 1, 2, 3aI, Beccles, Jersey, Taunton, B.A.O.R. and Dundee. The prominence of *Salm. heidelberg* and of *Salm. bredeney* is interesting in relation to the increasingly frequent implication of these types in food poisoning, as discussed in the report on Food Poisoning in England and Wales, 1957 (Report, 1958*a*).

The genesis of food-poisoning outbreaks and the results of experimental work with laboratory cultures (McCullough & Eisele, 1951*a*, *b*, *c*) both suggest that the ingestion of a large number of salmonellae, perhaps of the order of several million organisms, is required before food-poisoning results. Savage (1942) reached a similar conclusion with regard to *Salm. paratyphi* B from a careful study of outbreaks of paratyphoid fever. The isolation of salmonellae from sea water in the present committee's investigations is therefore to be considered more as evidence of wide dissemination of these organisms in the community than as an indication that these organisms when present in small numbers in sea water are a serious risk to health.

It should, perhaps, be pointed out here that, in assessing the significance of the isolation of salmonellae from sea water, and in particular in deciding whether this calls for urgent action in the way of improvements in sewage treatment, one cannot assume that even a secondary sewage effluent from a treatment plant would contain significantly fewer salmonellae than does crude sewage. Thus, Garber (1956) quotes an arithmetic mean coliform count of 400,000 per ml. on raw sewage reaching the Hyperion plant at Los Angeles, and a corresponding count of 212,000 per ml. on secondary effluents, a reduction of only about one-half. Full chlorination of sewage plant effluents would be necessary if virtual sterilization was required.

The health risks of bathing in sewage-polluted sea water

The committee is satisfied that, with the various channels of ascertainment used, not many cases of typhoid or paratyphoid fever in England and Wales with good presumptive histories of infection through sea bathing have been missed during the past 3 or 4 years. The evidence cited does suggest, however, that very occasionally such cases do occur. The two beaches where a fairly clear association between bathing and paratyphoid fever was demonstrated both showed median coliform counts of over 10,000 per 100 ml. One of these beaches, as already mentioned, had at one time warning notices dissuading bathers, and the foreshore was so dirty that bathing was very difficult except at high tide. In view of the discrepancy between the numbers of paratyphoid bacilli isolated from the sea-water samples examined and the large numbers of paratyphoid bacilli required to produce enteric fever in man, it seems probable that such occasional cases as do occur are infected not through ingestion of paratyphoid bacilli in the sea water but through contact with uncomminuted faecal masses that happen to have come from paratyphoid excreters.

The practical implication of the bathing history study on poliomyelitis patients and their controls is to cast doubt on the significance in the causation of poliomyelitis of a history that a patient with the disease had bathed so many days before the onset of symptoms. There are possible fallacies in an inquiry of this kind, one being that parents of sick children will probably recall the events immediately preceding the onset of illness with greater clarity than parents of healthy children. The latter are asked to give a history of events from what is to them an arbitrary date, i.e. the date of onset of illness in a patient whom they may not know. If it had been found that children with poliomyelitis had been recorded as having bathed more often than the control children, it would have been difficult to decide whether the difference was real or was due to a difference in the completeness of the histories from the two groups. The negative findings reported here probably mean that the histories from both groups were reasonably accurate and may be taken as an indication that bathing does not play a detectable part in the aetiology of poliomyelitis in a survey of the size reported. A survey of this type could clearly not prove that poliomyelitis was never caused by bathing, and in any case such a presumptive finding might be contradicted by future events, but the results of the survey give no indication that further investigations along these lines is likely to be fruitful except in the negative sense recorded.

The bacteriological grading of bathing beaches

Assessment of the contamination of bathing waters by sewage can be made in two main ways: first, by a sanitary survey of the sources of pollution and of the effect on pollution of factors such as tidal currents or prevailing winds, and secondly by bacteriological surveys of the kind undertaken by the present committee. Each method has its advantages and disadvantages. The sanitary survey concentrates among other things on visual assessment of the degree of gross pollution in an outfall area and of the meteorological and other factors affecting this. It includes therefore aesthetic judgements, and these alone may sometimes force general agreement that certain stretches of sewage-polluted bathing water are so foul as to require some action to improve the conditions that prevail. Again, a careful sanitary survey may point to unusual combinations of meteorological or other factors aggravating pollution at certain points on bathing beaches, thus giving information that only a very extensive bacteriological survey would uncover.

Observational surveys also have certain failings. First, they only measure peaks of pollution and can give no objective measure of average pollution. Secondly, they do not permit comparison of relative degrees of pollution on different bathing beaches. In this context, the committee has been surprised from time to time by the discrepancy between the pronouncements of a highly vocal public opinion on the degree of pollution of bathing waters in certain areas and the very moderate coliform counts demonstrated on samples from the same areas examined in the committee's investigations. Thirdly, a sanitary survey cannot give an adequate basis for the assessment of health risks. Under all these headings, carefully planned bacteriological surveys can offer useful supplementary information.

Provided due care is taken in the planning of bacteriological surveys and that the samples collected are representative of the degree of contamination to which bathers are exposed, the committee is of the opinion that a rough comparison of the degree of pollution of different bathing waters on the lines of Table 3, is legitimate and might be used in deciding on priorities in the provision of new sewer outfalls or of other improvements in sewage disposal in coastal towns.

The committee can, however, see no logical justification for the application of rigid bacteriological standards for bathing beaches, such as are used by a number of controlling authorities in the United States. In the first place, intensive study of a number of popular beaches has convinced us that by a judicious selection of sampling points and times, a considerable upgrading or downgrading of a given beach could easily be arranged at will. Secondly, as Garber (1956) has pointed out, public health authorities that set a given standard may find it very difficult to justify the choice of any particular figure. Perhaps the most defensible attitude is that underlining a certain Californian bacteriological standard, which is pitched fairly high because a lower one might pass as satisfactory some beaches that were aesthetically unsatisfactory, thereby discrediting the bacteriological standard. If, however, a bacteriological standard for bathing waters is applied, the implication is that beaches not conforming to it are unsatisfactory. If one then asks why they are unsatisfactory, the only obvious basis for judging them to be so is either aesthetic or that of danger to health.

No evidence has been obtained to suggest that a standard based on health risks is practicable. On the results of the studies described, it could be argued that bathing waters with median coliform counts of greater than 10,000 per 100 ml. occasionally cause paratyphoid fever, and that a standard of this order can be justified on health grounds, but it would be irrelevant to the great majority of beaches studied by the committee, median counts on which were well below this figure.

The isolation of a wide variety of salmonellae from sea water, however, and the occasional occurrence of paratyphoid fever as a result of bathing, in spite of the large infective dose probably required for disease to occur, both serve as a reminder that most of the pathogens in sewage probably reach it first in the excreta of individual excreters of these organisms. The point has been made in the discussion of sampling techniques that sea-water samples are to be considered as washings of a complex contaminated environment. Presumably, a more intensive bacteriological survey of bathing areas contaminated by the discharge of untreated sewage might have detected small aggregates of highly infective faecal masses. The comminution of these highly infective foci is clearly desirable. And here, perhaps, the aesthetic and the epidemiological arguments have a meeting point in the suggestion that a broad general policy of gradual improvement in the aesthetic aspect of bathing waters is epidemiologically sound, negligible though the risk of contracting disease in sewage-contaminated sea water would seem to be.

SUMMARY

1. Bacteriological surveys of more than forty popular bathing beaches around the coasts of England and Wales have been made during the past 5 years. The great majority of the beaches studied were subject to contamination with sewage.

2. A rough grading of the beaches studied gave a similar ranking order whether the results of the presumptive coliform test or faecal coli counts were used as the basis of grading.

3. Grading of beaches was valid only when surveys were carefully planned to ensure representative sampling from the areas on the beaches concerned where bathing actually took place.

4. The coliform test as used in the bacteriological examination of drinking waters was the main test procedure used but had certain limitations. Promising results with plate counts on relatively non-inhibitory media were obtained.

5. Various salmonella serotypes, notably *Salm. paratyphi B*, were isolated in small numbers from a high proportion of sea-water samples. The proportion of positive results for salmonella isolation increased from 13·3 % in samples with less than 1000 coliform organisms per 100 ml. to 40·1 % in samples with over 10,000 coliforms per 100 ml. Comparison of the numbers of salmonellae isolated with what is known of the minimum infective doses of these organisms suggested that very large volumes of sea water would require to be ingested for infection to occur.

6. Poliovirus was not isolated from a small series of sea-water samples examined. Because of the very large dilution factor, special concentration procedures would probably be required to isolate this virus from sea water.

7. Four cases of paratyphoid fever probably due to bathing were recorded. Surveys of the two associated beaches had given median presumptive coliform counts of more than 10,000 per 100 ml., and both showed gross macroscopic pollution with sewage.

8. A statistically controlled study of the bathing histories of 150 poliomyelitis cases in children living permanently by the seaside gave no evidence that bathing had played any part in causing the disease.

GENERAL CONCLUSIONS

The following general conclusions are drawn as a result of the investigations reported:

(i) That bathing in sewage-polluted sea water carries only a negligible risk to health, even on beaches that are aesthetically very unsatisfactory.

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(ii) That the minimal risk attending such bathing is probably associated with chance contact with intact aggregates of faecal material that happen to have come from infected persons.

(iii) That the isolation of pathogenic organisms from sewage-contaminated sea water is more important as evidence of an existing hazard in the populations from which the sewage is derived than as evidence of a further risk of infection in bathers.

(iv) That, since a serious risk of contracting disease through bathing in sewage-polluted sea water is probably not incurred unless the water is so fouled as to be aesthetically revolting, public health requirements would seem to be reasonably met by a general policy of improving grossly insanitary bathing waters and of preventing so far as possible the pollution of bathing beaches with undisintegrated faecal matter during the bathing season.

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APPENDIX. CALCULATION OF PROBABLE COUNTS

(1) The following table, based on that of Hoskins (1934), was used for the calculation of probable counts from the results of 6-tube, 3-dilution tests with two tubes per dilution each containing 1, 0·1 and 0·01 ml. respectively of sea water.

No. of positive tubes			
1 ml.	0·1 ml.	0·01 ml.	M.P.N./100 ml.
0	0	1	45
0	0	2	90
0	1	0	46
0	1	1	92
0	1	2	140
0	2	0	94
0	2	1	140
0	2	2	190
1	0	0	60
1	0	1	120
1	0	2	190
1	1	0	130
1	1	1	200
1	1	2	280
1	2	0	210
1	2	2	370
2	0	0	230
2	0	1	500
2	0	2	950
2	1	0	620
2	1	1	1,300
2	1	2	2,100
2	2	0	2,400
2	2	1	7,000
2	2	2	24,000+

(2) The following table gives M.P.N. figures, and approximate 5% confidence limits, for a dilution test with ten tubes each containing 0·1 ml. of the sample.

No. of positive tubes	Lower limit (in 39 out of 40 samples)	M.P.N./100 ml.	Upper limit (in 39 out of 40 samples)
0	—	—	369
1	15	105	749
2	56	223	895
3	114	357	1110
4	190	511	1380
5	283	693	1690
6	400	916	2100
7	548	1200	2640
8	743	1610	3490
9	1030	2300	5160
10	1180	—	—

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