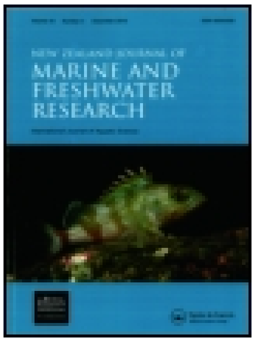

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Faecal bacteria from sewage effluent in sediments around an ocean outfall

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Abstract A study of organisms around an ocean sewage outfall showed that bacteria of faecal origin could be detected in the sediment up to 8 km from the outfall. The direction of the currents and wind affected distribution, and even when bacteria were not detected in the water column they were detected in the sediments. The implications of these results for recreational areas and shellfish beds are discussed.

Keywords faeces; bacteria; sewage; effluent; sediments; water; faecal coliforms; marine

INTRODUCTION

It is common practice in many parts of the world, including New Zealand (OECD 1981), to dispose of treated and untreated sewage into the ocean. Any subsequent bacteriological monitoring of the ocean receiving such effluent is usually confined to testing water column samples. Surprisingly little attention has been paid to the possible survival of organisms of faecal origin in the ocean sediments and the implications of this survival (Erkenbrecher 1981). Some time ago Weiss (1951) and Rittenberg et al. (1958) reported the presence of such organisms in sediments, and Gerba and McLeod (1976) showed that bacteria of faecal origin survived longer in sediments than in the water column. Goyal et al. (1977) subsequently found that numbers of faecal coliforms and *E. coli* were higher in the sediments than in the overlying water in canal systems on the Texas Coast. These findings are of particular interest in the light of the work of Grimes (1975) who showed that dredging caused the release of sediment bound faecal coliforms into the water column and of Roper and Marshall (1974) who reported that faecal organisms could be desorbed into the water column from sediments.

The possibility has to be considered that even though faecal bacteria may be removed from the water column because of various factors (Carlucci & Pramer 1959, 1960; Mitchell 1968) such organisms may survive in sediments and be subsequently released by disturbances of the sediments either by natural or man made influences. Such release of faecal organisms could jeopardise the safety of nearby beaches and shellfish beds. In view of the few studies on survival of faecal bacteria in marine sediments a study was begun in 1979 to find if bacteria of faecal origin could be detected in the sediment and overlying water near an ocean sewage outfall on the Otago Coast.

MATERIALS AND METHODS

Sampling sites

Wastes from Dunedin City, until June 1983, were deposited untreated into the open sea at Lawyers Head on the Otago Coast of the South Island of New Zealand (Fig. 1) at the rate of 11×10^6 *l* day^{-1}, except there were intermittent periods of treatment from 1982 during the commissioning of a treatment plant. The plant came into full commission in mid-1983. The site of discharge is an exposed ocean coast where the predominant current is parallel to the coast and from a southerly direction.

Collection of samples

No fixed sampling stations could be established because of the nature of the coast and the weather conditions which at times combined to restrict boat access (see Fig. 2–4).

Sediment and water samples were collected on eight trips between 6/12/79 and 8/7/83 from the University of Otago research vessel *Munida* within a 50 km² area around the sewage outfall. Water column samples were collected into sterile glass containers or polythene bags using a device that could be opened at depth and closed before raising the sample. Sediment samples were collected using an

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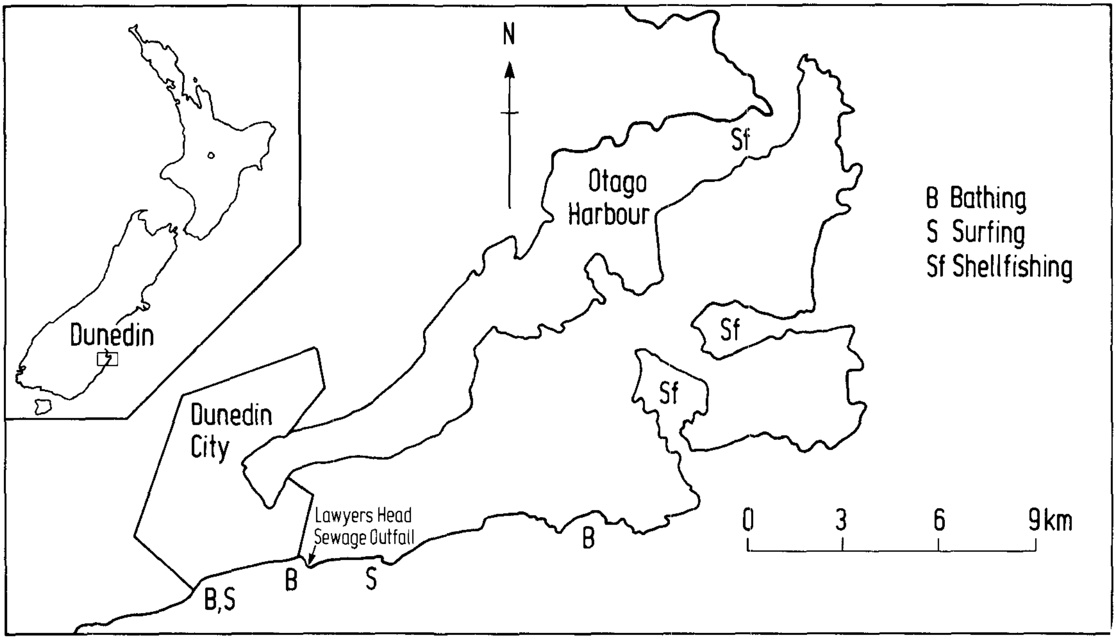

Fig. 1 Map of Otago Peninsula showing the location of the Lawyers Head sewage outfall in relation to recreational beaches and major shellfishing areas.

anchor dredge (as the sample is raised, water pours off and the inside of the large sample can be subsampled when above the water) and transferred to polythene bags. All samples were processed within 12 hours of collection and were stored at 4°C until processed.

Bacteriological analysis

The methods used for estimation of numbers of indicator bacteria were based on the recommendations of the New Zealand Microbiological Society's Coliform Committee (1976). Oxoid Minerals Modified Glutamate (MMG) was used in a five-bottle method to estimate presumptive coliforms (PC). Inocula from positive bottles were transferred to Difco Lauryl Sulphate Tryptose Broth (LSTB) and incubated at 44.5 ± 0.5°C in a water bath, for estimation of faecal coliforms (FC).

Material from positive tubes in the FC test was streaked on to Levine's Eosin Methylene Blue Agar (EMB) plates and, after incubation, a selection of colonies which showed a dark metallic sheen was purified. Each isolate was inoculated into biochemical test media for the IMViC series and into lactose broth, nutrient broth, and on to nutrient agar, the latter two to establish motility, Gram reaction, and spore production. The results from these tests allowed estimation of presumptive *E.*

Table 1 Most probable number of presumptive coliforms (PC) in sediment (10 g) and water (100 m*l*) samples collected on Trip 1 (6/12/79) from around the Dunedin sewage outfall. NS = no sample.

Sampling site (See Fig. 2A)	Sediment	Water	Depth (m)
1	0	NS	
2	500	NS	
3	NS	6000	6
4	16 000	NS	
5	2500	NS	
6	3500	NS	
7	6000	NS	

Table 2 Most probable number of presumptive coliforms (PC) and faecal coliforms (FC) in sediment (10 g) and water (100 m*l*) samples collected on Trip 2 (18/2/80) from around the Dunedin sewage outfall.

Sampling site (See Fig. 2B)	Sediment PC	Sediment FC	Water PC	Water FC	Depth (m)
1	170	0	0	0	5
2	1400	20	4	0	5
3	350	0	1600	25	5
4	18 000+	140	1800+	450	5
5	18 000+	9000	0	0	5
6	1700	20	0	0	10
7	450	0	4	0	30

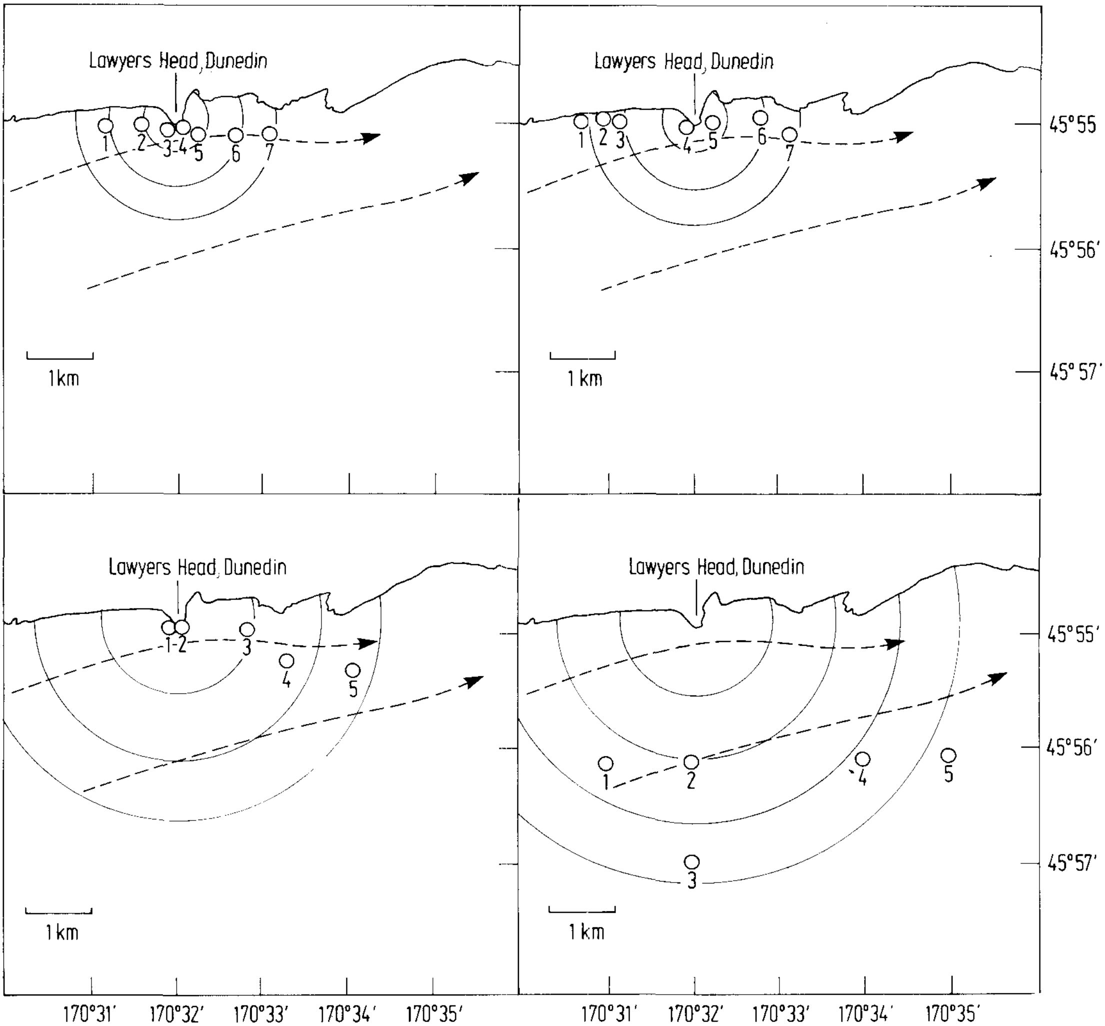

Fig. 2 Sampling sites for Trip 1 (6/12/79) (2A), Trip 2 (18/2/80) (2B), Trip 3 (10/4/81) (2C), and Trip 4 (15/12/81) (2D).

Table 3 Most probable number of presumptive coliforms (PC) and faecal coliforms (FC) in sediment (10 g) and water (100 m*l*) samples collected on Trip 3 (10/4/81) from around the Dunedin sewage outfall. NS = no sample.

Sampling site (See Fig. 2C)	Sediment PC	Sediment FC	Water PC	Water FC	Depth (m)
1	1300	20	50	0	20
2	1300	350	450	250	6
3	9000	250	0	0	11
4	350	0	0	0	37
5	NS	NS	20	0	36

coli. From these procedures, a most probable number of PC, FC, and presumptive *E. coli* could be estimated in water and sediment samples (NZMS 1976). Only organisms that were Gram negative, non-sporing, lactose fermenting, and ++−− in the IMViC series were presumed to be *E. coli*.

RESULTS

The collection of samples of sediment and water close to the outfall and the shore, along the Otago Coast, posed a difficult problem because of the

Table 4 Most probable number of presumptive coliforms (PC), faecal coliforms (FC), and presumptive *Escherichia coli* in sediment (10 g) and water (100 m*l*) samples collected on Trip 4 (15/12/81) from around the Dunedin sewage outfall. NS = no sample.

Sampling site	Sediment			Water			Depth
(See Fig. 2D)	PC	FC	*E. coli*	PC	FC	*E. coli*	(m)
1	170	40	40	1600	350	350	5
2	1700	500	170	600	6	6	6
3	NS	NS	NS	25	25	25	32
4	350	110	110	0	0	0	8
5	350	50	50	0	0	0	16

Table 5 Most probable number of presumptive coliforms (PC), faecal coliforms (FC), and presumptive *Escherichia coli* in sediment (10 g) and water (100 m*l*) samples collected from around the Dunedin sewage outfall on Trip 5 (9/3/82).

Sampling site	Sediment			Water			Depth
(See Fig. 3A)	PC	FC	*E. coli*	PC	FC	*E. coli*	(m)
1	250	250	80	12	12	0	5
2	1300	500	200	1800+	1600	900	6
3	0	0	0	0	0	0	40
4	0	0	0	0	0	0	60
5	50	0	0	4	4	2	60

nature of the coast and the prevailing weather. For reasons of economy, where possible, collections were made when the *Munida* was being used for the collection of other scientific data and this together with weather conditions meant that collections for our study were irregular.

The results obtained (Table 1) from samples collected on 6/12/79 (Fig. 2A) indicated that PC could be detected in the sediments and in the single water sample collected at that time by the proposed methods. Further samples were obtained (18/2/80) from approximately the same sampling sites (Fig. 2B). On both sampling dates PC and FC estimates were higher east of the outfall (Tables 1, 2).

No FC could be detected in the water column at 3 sites on the second trip but could be detected in sediments collected at the same sampling points. Not only does this indicate that organisms of possible faecal origin are deposited to the seabed but it also suggests they survive there when organisms in the water column are destroyed. This result was repeated for samples collected on Trip 3 on 10/4/81 (Fig. 2C,Table 3).

Following the reports that the FC test can detect organisms of other than faecal origin (Hendricks 1970; Duncan et al. 1981), it was decided to confirm the presence of *E. coli* in the next samples. PC and FC had been detected some distance from the outlet, therefore the next set of samples was collected at least 2 km from the outlet (Fig. 2D). The results from these samples are given in Table 4. Presumptive *E. coli* was detected in all sediment samples even those 3 km from the outlet. Not all water samples were positive for PC, FC, and *E. coli* even when a positive result was obtained for the sediment samples collected at the same site. Water sample 3 was of interest. The master of the *Munida* followed what appeared to be a slick of effluent on a calm sea. This water sample proved to be positive for PC, FC, and *E. coli* even though the sample was taken at 32 m depth and 3.5 km from the outlet.

The higher PC and FC east of the outlet (Tables 1, 2) indicate that the discharged effluent is being carried by currents and wind in that direction. The main currents in the area are up along the coast (an easterly direction at this point of the coast) and winds are predominantly from the south or southwest. On occasion, however, strong northerlies blow for several days at a time. The effect of current and wind on effluent is also seen in Table 5. (Trip 5 on 9/3/82, Fig 3A.) Detection of *E. coli* in water sample 5, collected 8.5 km from the outlet could only be accounted for by assuming that effluent has been carried that distance by current and/or wind or that there had been discharge of material from a passing boat. The depth at which the sample was collected would seem to preclude the latter situation.

A further set of sediment samples was collected at varying distances from the sewage outlet (Trip 6 on 17/11/82, Table 6, Fig 3B) and the results

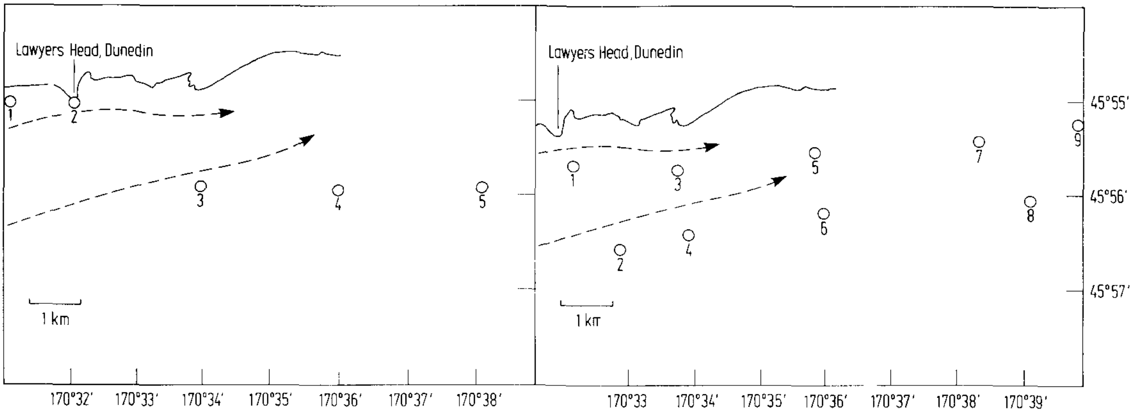

Fig. 3 Sampling sites for Trip 5 (9/3/82) (3A) and Trip 6 (17/11/82) (3B).

support the previous observations that effluent is carried some distance from the outlet; indeed *E. coli* was detected nearly 10 km from the discharge point.

During 1981 and 1982 the Dunedin sewage was treated intermittently by primary treatment and chlorination and the plant was commissioned finally in mid 1983. The treatment to that date had resulted in somewhat lower PC and FC (Tables 7 & 8) numbers in samples collected on Trips 7 and 8 (Fig. 4A, B). The *E. coli* numbers were lower in the water and sediment compared with previous results, although on occasions numbers were still quite high in water samples (Table 8) close to the outfall.

Table 6 Most probable number of presumptive coliforms (PC), faecal coliforms (FC), and presumptive *Escherichia coli* in sediment samples (10 g) collected around the Dunedin sewage outfall on Trip 6 (17/11/82).

Sampling site (See Fig. 3B)	Sediment PC	FC	*E. coli*	Depth (m)
1	3000	140	60	20
2	1700	20	20	55
3	9000	350	40	22
4	20	20	20	50
5	3500	1300	90	45
6	350	0	0	55
7	3500	200	110	40
8	250	0	0	58
9	1300	90	20	50

DISCUSSION

The disposal of sewage from increasingly urbanised populations is causing problems in many parts of the world. Although New Zealand has an admirable record in providing reticulation for sewage collection (OECD 1981), the practice of disposing of untreated and partially-treated sewage into the ocean requires careful assessment.

Discharge into the ocean is condoned because of the belief that "the sea itself functions as an enormous natural purification system" and that "a rational appreciation of resources inevitably leads to the conclusion that marine sewage disposal is a practical, economic, and efficient use of renewable resources" (OECD 1981). The same OECD report states "of 31 sea outfalls, few discharge near beaches and there is in consequence little evidence in the form of epidemiological data of danger to human health".

Table 7 Most probable number of presumptive coliforms (PC) and faecal coliforms (FC) in sediment (10 g) and water (100 m*l*) samples collected on Trip 7 (29/4/83) from around the Dunedin sewage outfall.

Sampling site (See Fig. 4A)	Sediment PC	Sediment FC	Water PC	Water FC	Depth (m)
1	500	110	50	35	7
2	250	70	50	35	7
3	250	80	250	50	6
4	130	0	80	13	7
5	350	8	17	13	12
6	500	80	25	5	20

It must be said however, that apart from the fact that it is difficult to correlate infection in humans with water contamination as both disease occurrence and water pollution are usually sporadic, there is the additional complication when attempting to

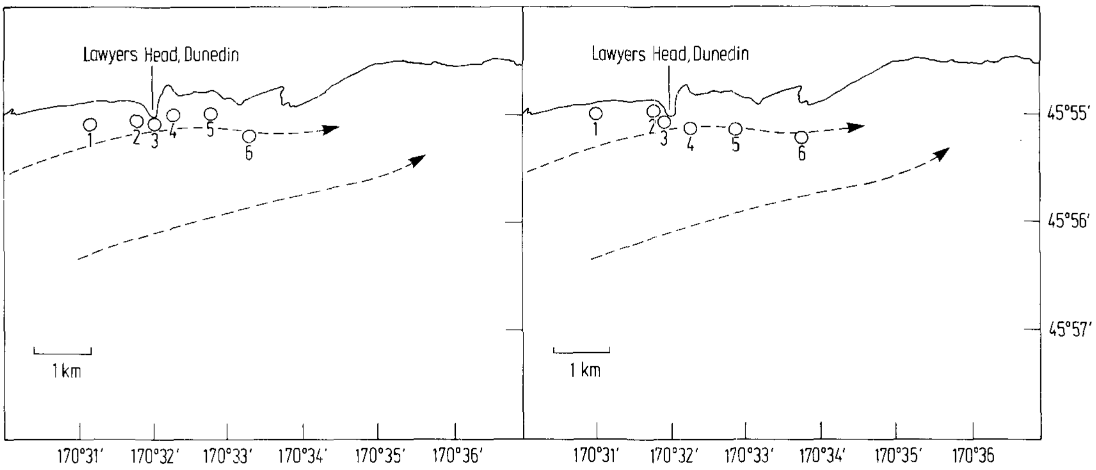

Fig. 4 Sampling sites for Trip 7 (29/4/83) (4A) and Trip 8 (8/7/83) (4B).

Table 8 Most probable number of presumptive coliforms (PC), faecal coliforms (FC), and presumptive *Escherichia coli* in sediment (10 g) and water (100 ml) collected on Trip 8 (8/7/83) from around the Dunedin sewage treatment outfall.

Sampling site	Sediment			Water			Depth
(See Fig. 4B)	PC	FC	*E. coli*	PC	FC	*E. coli*	(m)
1	110	0	0	28	17	6	11
2	170	0	0	22	6	0	7
3	300	80	0	120	8	2	6
4	350	110	0	350	32	20	7
5	9000	50	0	1600	900	250	13
6	80	20	0	6	4	0	20

obtain epidemiological evidence that not all diseases transmitted by this route are reported to the Health Department.

Defence of ocean sewage disposal is further based on testing of the water column for bacteria of faecal origin. These faecal bacteria are removed by various processes (Carlucci & Pramer 1959, 1960; Mitchell 1968) and their absence from the water column leads to the assumption that the water is safe. Two things are ignored; the possible presence of viruses in the water column and the likelihood that bacteria of faecal origin and viruses may be surviving in the sediment. That faecal bacteria do survive is supported by the present study and by the work of Hood and Ness (1982) who have shown in laboratory studies that *E. coli* and *Vibrio cholerae* survived better in estuarine sediments than in water.

Not only have the bacteria been shown to survive in sediments in this study but they were also found at considerable distances from the outfall. Subsequent dispersal of these sediments by rough weather could result in the resuspension of the bacteria and as the outfall is within a kilometre of recreational beaches a potential hazard to users could be created.

That partial treatment of sewage reduces numbers of PC, FC, and *E. coli* is of significance but whether virus numbers are also reduced has yet to be established. The report that bacteria survive more readily in sediments below 15°C is another facet of sewage disposal into the ocean that must be considered carefully. The question must be asked as to whether it is wise to continue the practice of discharging sewage into the sea if there is a possibility that shellfish beds even at a considerable distance from the discharge could be contaminated. A burgeoning cultivated shellfish industry must not be placed at risk by such a practice and the attention drawn by the OECD (1981) report to the danger of contamination of shellfish beds from near shore sewage outfalls must not be ignored.

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