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The GEEP Workshop: field sampling

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ABSTRACT: Field sampling for the GEEP Workshop was carried out in Frierfjord and Langesundfjord in southern Norway. Both these fjords are stratified with shallow sills. The Skiens river enters the Frierfjord and influences both stratification and pollution of the fjords. Chemical contamination of water and sediments are well documented; a decreasing contaminant gradient can be observed from the top of the Frierfjord towards Langesund Bay. Procedures for sampling material for the workshop are described.

FRIERFJORD AND LANGESUNDFJORD

Frierfjord and Langesundfjord are located near the outer Oslofjord in southern Norway, and are open to the Skagerak (Fig. 1). Like the Oslofjord, the Frierfjord and Langesundfjord (Fig. 2) are stratified having shallow sills (Fig. 3) and a strong fresh water influence. The Skiens river, entering the Frierfjord, has an average runoff of 270 $m^3 s^{-1}$ and causes the salinity of the uppermost 1 to 7 m of the Frierfjord to be as low as 1 to 5 ‰ (Molvaer 1975).

Three distinct water masses in the Frierfjord are recognized: surface, intermediate, and deep water (Fig. 4). The depth of the surface layer depends on the river runoff, and the flow from this layer enters Langesundfjord from the western side of the Frierfjord (total water exchange in the Frierfjord occurs over 1.5 to 5 d, Molvaer 1975). The Frierfjord surface water influences the surface layer in Langesundfjord, which has a salinity between 2 and 26 ‰ outside Brevik. The temperature of this surface layer varies between 0 and ca 20 °C.

The intermediate layer in the Frierfjord normally covers a depth from 8 m to ca 30 m. The Brevik sill is at a depth of 23 m and, outside Brevik, the intermediate layer is normally found down to 50 to 60 m. Hydrographic conditions can, however, raise this layer to a depth of less than 20 m. The intermediate layer in the Frierfjord is characterised by a salinity range of 25 to 34 ‰ and a temperature of 3 to 16 °C.

The deep water in the Frierfjord is found from a depth of about 30 m to the bottom (maximum depth 98 m) and is homogeneous in salinity and temperature (33 to 34 ‰ and 6 to 8 °C). Exchange of deep water occurs every 2 or 3 yr, between January and March. Meteorological events affecting the Skagerak and the North Sea determine the extent of the exchange of deep water through the Brevik sill. The bottom water is often anoxic for long periods in summer and autumn each year.

In Langesundfjord, the deep water is normally located between 60 to 70 m and the bottom. This water (salinity 34 to 35 ‰; temperature 6 to 12 °C) is changed far more frequently than in the Frierfjord due to the sill being at 50 m (Fig. 3) making deep-water exchange possible every 4 to 6 mo.

Skiens river and Frierfjord are affected by many sources of pollution, such as heavy industry and waste from a dense population (Rygg 1985). Although some industries in the area have reduced their waste discharge during the last decade, there is still considerable pollution from organic waste. The contents of organic contaminants are high in animals (Rygg 1985) and sediments (Skei 1981) in the area, and wood fibres, industrial nutrient waste and municipal waste water contribute to the production of anoxic deep water in the summer.

Due to various chemical industries and the former pulp mill industry in the Skiens river, mercury is still present in large amounts in the sediment (Molvaer 1979, Rygg 1985), especially in the Gunnekleivfjord (Fig. 2). This is a semi-enclosed 'basin' which acts as a reservoir for mercury in the sediment, providing a source of continuous contamination to the Frierfjord,

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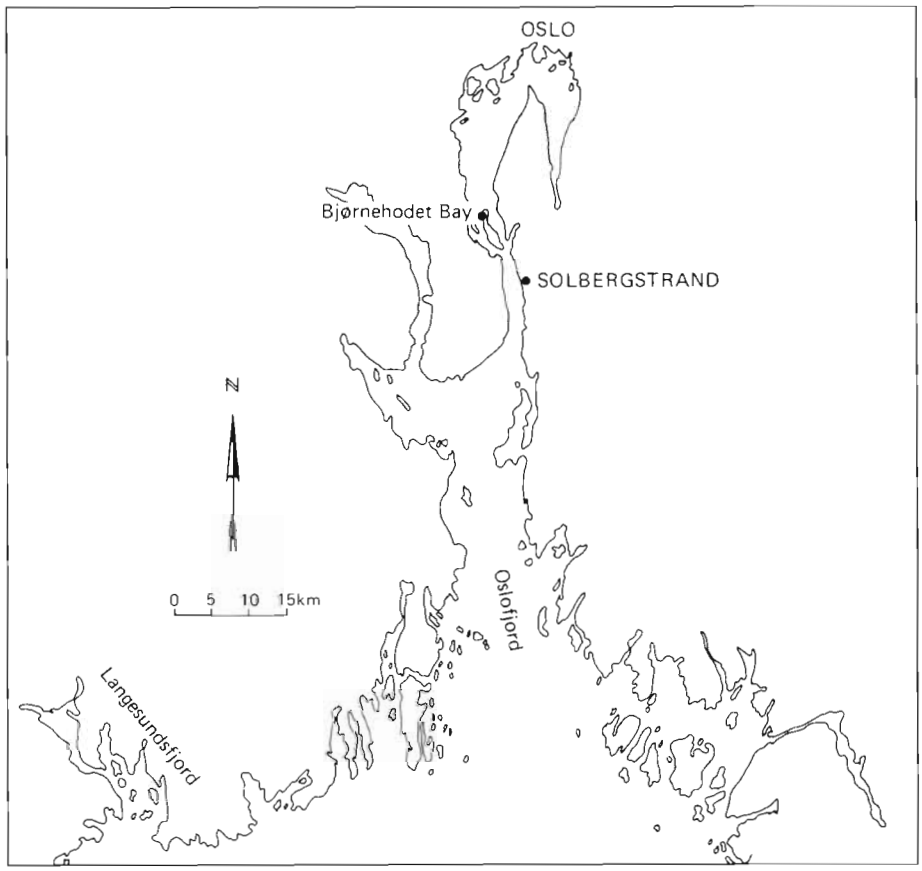

Fig. 1. Oslofjord area with Langesundfjord, Solbergstrand and Bjørnehodet Bay (cf. Bakke et al. 1988) indicated

Table 1. Characteristics of surface water (after Molvaer 1979). Means and ranges

Location	Secchi depth (m)	$NO_2 + NO_3$ ($\mu g\ l^{-1}$)	HCB ($\mu g\ l^{-1}$)
Frierfjord	3.0 (1.2, 5.3)	580 (170, 880)	18 (6, 33)
Langesundfjord	4.5 (1.8, 10.5)	370 (180, 520)	8 (3, 20)
Langesund Bay	8.0 (2.0, 20.0)	120 (20, 410)	2 (1, 4)

Table 2. Selected chlorinated hydrocarbons and total PAH concentrations ($\mu g\ g^{-1}$) in dry sediments (0 to 5 cm: Molvaer 1979; 0 to 2 cm: Skei 1981)

Location	5CB	HCB	OCS	10CB	PAH
0–5 cm					
Frierfjord	1.130	6.290	1.130		
	0.170	0.830	0.320		
Langesundfjord	0.003	0.040	0.006		
	0.002	0.006	0.003		
0–2 cm					
Frierfjord	5.6	30.8	3.1	1.3	32.2
Langesundfjord	1.8	7.4	0.2	0.2	4.3

even though the largest source of discharge was stopped a decade ago.

The Langesundfjord is influenced by the contaminated surface water from the Frierfjord and the outlets of municipal waste water from the Brevik area. This creates a contamination gradient out to Langesund Bay in the south. Low oxygen concentrations in the Langesundfjord deep water probably result from the high organic input to the fjord.

The Norwegian Institute for Water Research (NIVA) has, over recent years, investigated the environmental conditions in the Frierfjord and Langesundfjord area (Molvaer 1979, Rygg 1979, 1981, 1985). The data in Tables 1 to 4 illustrate the existence of a contamination

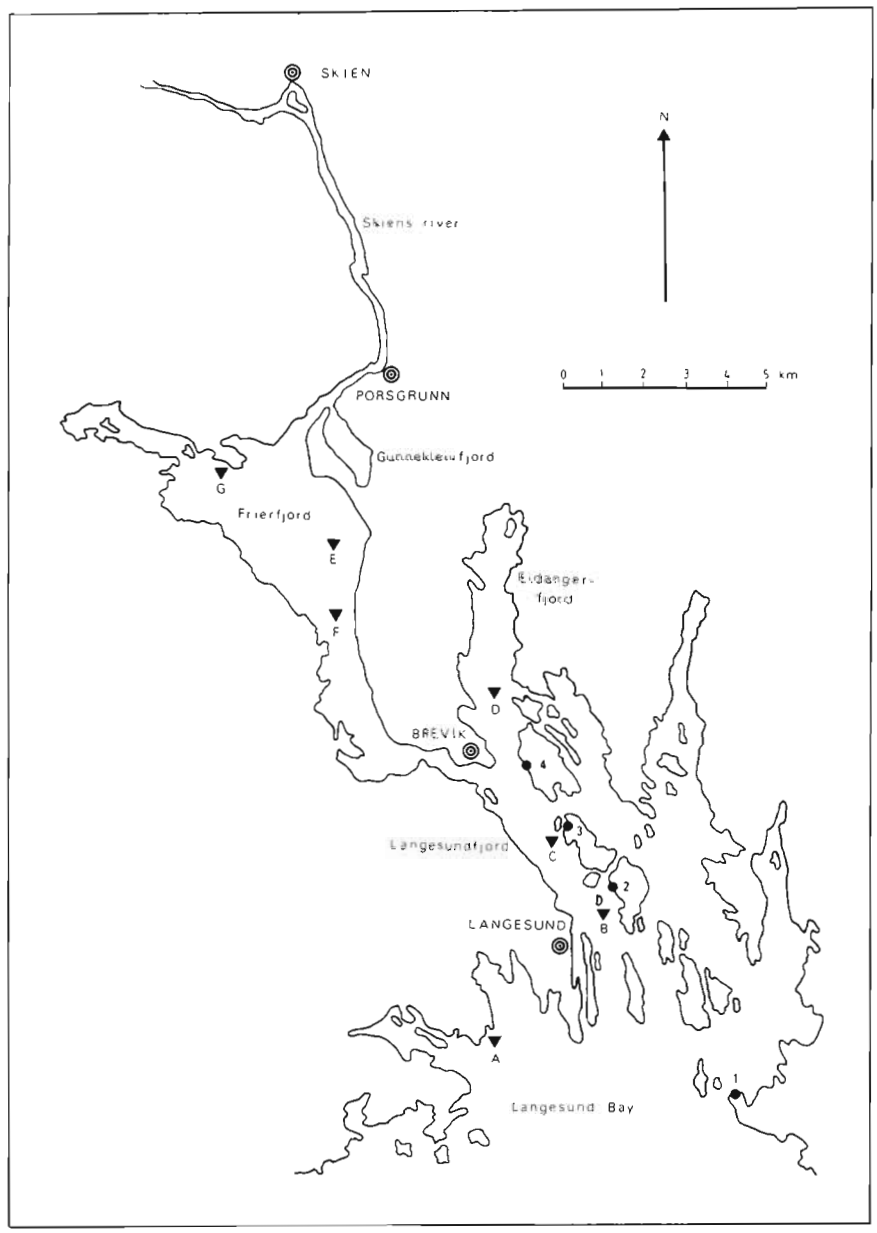

Fig. 2. Field sampling sites for *Mytilus edulis, Carcinus maenas, Littorina littorea* and *Platichthys flesus* in Langesundfjord (Sites 1 to 4, circles) and for benthic faunal communities in Frierfjord, Langesundfjord and Langesund Bay (Sites A to G, triangles)

Table 3. Metal concentrations (μg g^{-1}) in dry sediments (after Molvaer 1979)

	Hg	Zn	Pb	Cd	Cu	Mn	% Fe	Ni	% Org.
0–2 cm									
Frierfjord	4.9	398	191	4.2	65	3450	2.3	35	
	1.7	154	49	1.5	17	2000	2.3	22	
Langesundfjord	2.1	155	98	4.0	37	4700	2.2	29	
Langesund Bay	0.6	95	47	2.2	15	290	2.7	41	
	0.7	80	4	<1.5	16	590	1.8	16	
0–1 cm									
Frierfjord	3.4	494	260	5.1	89	43950	2.6		29.4
	4.6	529	214	3.8	87	1390	2.6		34.0
Langesundfjord	1.2	266	188	0.4	61	11627	3.0		15.4

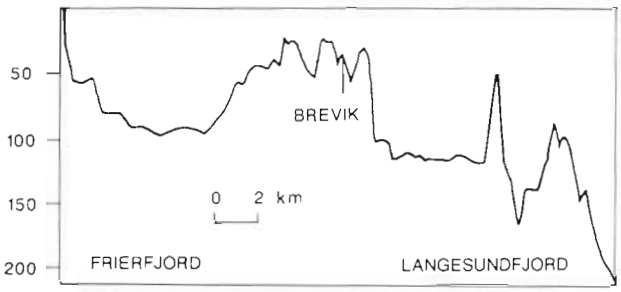

Fig. 3. Depth profile (m) of Frierfjord and Langesundfjord. (After Molvaer 1979)

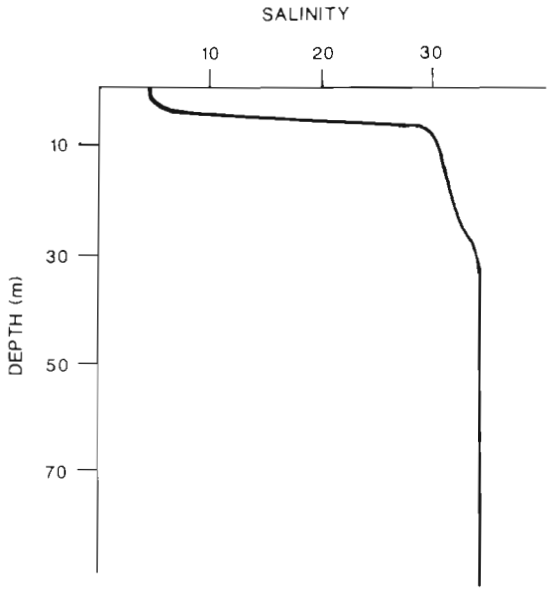

Fig. 4. Stratification of water column in Frierfjord. (After Molvaer 1979)

gradient from Frierfjord to Langesund Bay, as it was known prior to the GEEP Workshop. Most of the data are taken from Molvaer (1979). Rygg (1985) indicates that little improvement with respect to water quality and environmental contamination has occurred in the area since 1979. Data quoted in these tables for 'Frierfjord' are taken near Sites E and F (Fig. 2); 'Langesundfjord' refers to sites near B and C, and 'Langesund Bay' is the area between Sites 1 and A.

SAMPLING

Sediment, bacteria, meiofauna and macrofauna

In January 1986 a cruise was made to the Frierfjord/Langesundfjord area with F/F 'Trygve Braarud' from the University of Oslo. At each of the 6 stations (A, B, C, D, E and G; Fig. 2), seven 0.1 m^2 Day-grab samples were taken. At Station F the bottom sediment was anoxic and had a fluid consistency, hence grab sampling was impossible. The volume of each grab sample was recorded and the samples were sieved on meshes of 5 and 1 mm. The material was then fixed in 4 % formalin. Samples for physical analysis of the sediments were taken from 2 of the Day grabs at each site; the results are given in Table 5.

Meiofauna and bacterial samples were taken during a joint IMER-University of Oslo cruise in April 1986. Five replicate meiofauna samples from a Craib corer (Craib 1965) were collected from each of 6 stations: A, B, C, D, E, F (G not included). The core was 5.65 cm in diameter and 8 cm deep; samples were fixed in 4 % formalin. The overlying water in the cores was filtered through a sieve of 63 µm mesh, and material retained

Table 4. Concentrations (µg g^{-1} dry wt) of metals and hydrocarbons in organisms (*Fucus vesiculosus:* Molvaer 1979; *Cancer pagurus* and *Mytilus edulis:* Rygg 1985). The values for *C. pagurus* are averages over 1977–1980. For locations of Sites 1, 2 and 4 see Fig. 2 (Sites 1 to 4 were designated A3, A6, B4, A9 by Rygg 1985)

	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Hg	Pb	HCB	OCS	DCB	PAH
F. vesiculosus													
Frierfjord	< 5	570	100	8	9	210	1.1	0.20	3				
	–	2500	250	11	17	350	2.8	0.36	10				
Langesundfjord	< 5	460	65	< 10	7	170	< 2	0.12	< 10				
	–	1200	150	< 10	8	240	< 1	0.12	< 10				
Langesund Bay	< 5	300	70	< 10	4	62	< 2	0.06	< 10				
	–	250	70	< 10	5	130	< 1	0.06	< 10				
C. pagurus													
Frierfjord					161	211	4.1	0.92	1.8	0.41	0.20	0.45	
Langesundfjord					129	185	3.7	0.35	0.9	0.07	0.03	0.06	
M. edulis													
Site 1													10.3
Site 2													21.8
Site 4													30.7

Table 5. Physical characteristics of sediments collected (Jan 1986) for benthic community analysis at the workshop. For site locations see Fig. 2

Site	Depth (m)	Grain size Ø scale, mean ± SD	Silt/clay %
A	76	5.70 ± 1.75	90.9
		5.88 ± 1.67	93.1
B	113	5.15 ± 2.16	69.9
		4.69 ± 2.14	54.5
C	108	5.88 ± 1.75	91.7
		5.92 ± 1.74	91.7
D	101	6.00 ± 1.64	95.1
		5.99 ± 1.64	94.7
E	22	5.76 ± 1.76	88.6
		5.74 ± 1.86	83.1
G	26	5.98 ± 1.81	89.3
		5.62 ± 1.88	88.8

on the sieve was backwashed into the respective sample containers. Before the formalin was added, a 2 cm^3 subsample was taken for bacterial analysis from each core, to which was added 8 ml of filtered 4 % glutaraldehyde.

Epibenthos sampling sites

An exploratory trip to the Langesundfjord was made in May 1986 to locate sampling sites for the workshop in August. The criteria for choosing the sites were: (1) they should lie, where possible, along the gradient where the sediment samples were taken in January; (2) an adequate number of individuals of each species required for the workshop should be available; and (3) the sites should be suitable for sampling with nets and the beach seine used to catch flounders *Platichthys flesus*.

No sites in Frierfjord satisfied all these criteria, and convenient sampling sites were found in Langesundfjord, as follows (Fig. 2).

Site 1. A shallow, north facing beach with boulders and sandy sediment located in the outer part of the Langesundfjord. This was the most wave- and wind-exposed sampling site. Dense populations occurred of all required species. Algae such as *Cladophora* sp., *Ulva lactuca, Ceramium* sp., *Fucus* sp. and *Chondrus crispus* were also abundant.

Site 2. A small, muddy beach facing west between small rocks and islands. This was the most sheltered sampling site, with mudflats nearby which contained high densities of the bivalve *Mya* sp. In addition to the green and brown algae *Enteromorpha* sp. and *Fucus serratus, Ulva lactuca* was also present on the rocky areas. A moderately dense population of *Littorina littorea* and *Mytilus edulis* occurred.

Site 3. A small, sandy beach, facing west between 2 islands and fairly well-sheltered. *Enteromorpha* sp. was abundant in August, together with patches of *Fucus serratus*. The density of winkles was low but reasonable densities of mussels occurred at this site.

Site 4. A flat sandy beach, facing west into the Langesundfjord, sheltered from wind-induced waves, but probably exposed to waves generated by ship traffic. The shore had boulders and jetties which in August were covered with *Enteromorpha* sp. and *Cladophora* sp. *Littorina littorea* and *Mytilus edulis* were loosely attached to the substrate, and the sand on the beach contained oil or asphalt, which stuck to ropes and clothing. This locality had the lowest densities of winkles and mussels.

Sampling during the workshop

All field sampling in the Langesundfjord was carried out during 11 to 14 August. The strategy adopted was to catch as many flounders *Platichthys flesus* as possible with a beach seine in the evening, and then to collect *Mytilus edulis, Carcinus maenas* and *Littorina littorea*. The flounders were handled as carefully as possible and kept in large containers with seawater brought from the sampling site to the vessel. Crabs and mussels were caught in the sublittoral by SCUBA diving, and the winkles picked from the littoral zone. After sunset, about 1000 m of fishing nets were deployed in order to catch further flounders. These nets were hauled early the following morning.

The animals caught in the evening were kept in 300 to 500 l aquaria with running sea water onboard the research vessel F/F 'Trygve Braarud'. All animals from one site were transported to Oslo by car as early as possible the morning after sampling. The rest of the morning was used for clearing the nets and preparing for the next sampling. Sampling at the next site started again in the afternoon. This strategy made it possible to sample all 4 sites (1, 3, 2 and 4) within 4 d, in that order.

Flounders were transported to Oslo in large plastic bags (30 l) filled with seawater and immersed in ice. The bags were flushed with oxygen, then sealed.

Table 6. Numbers of epibenthic animals sampled for the workshop (Aug 1986) at field Sites 1 to 4 (see Fig. 2)

Site	*Platichthys flesus*	*Littorina littorea*	*Mytilus edulis*	*Carcinus maenas*
1	60	160	400	50
2	12	150	350	50
3	30	150	400	70
4	25	150	350	35

Table 7 Timetable of the field sampling programme in Frierfjord/Langesundfjord; all dates are for 1986

Date	Event	Details of sampling
21–22 Jan	Benthic macrofaunal sampling at A–E, G	7 Day grabs (0.1 m^2) per site, with 2 subcores for sediment structure analysis
	Sediment chemistry sampling at A–E, G	3 Niemisto cores per sites (2 cm deep), analysed for PAHs and metals
24 Apr	Benthic meiofaunal and bacterial sampling at A–F	5 Craib cores (24.6 cm^2, 8 cm deep) per site, each subsampled for bacteria
Mid-May	Pilot sampling to determine sites for epibenthos collection in August	
→ Aug	Benthic abundance/biomass data prepared at Oslo (macrofauna), Gent (meiofauna) and Dartmouth (bacteria)	Analysis per site of 4 cores for macrofauna and meiofauna groups, 3 for copepods and 2 for nematodes
8–11 Aug	Participants arrive for workshop	
11–12 Aug	Overnight collection of *Platichthys flesus, Mytilus edulis, Carcinus maenas* and *Littorina littorea* from Site 1 and transportation to Oslo by mid-morning	Flounder caught by net and beach seine; mussels and crabs from the sublittoral, winkles from the littoral
	Mussels and crabs transported to Bergen for PAH and PCB analysis; mussels and fish to Oslo for metal chemistry	Mussels and crabs were a random subset of the total collection; chemistry on fish used the same individuals as the biochemistry
12–13 Aug	Sampling from Site 3, as above	
13–14 Aug	Sampling from Site 2	
14–15 Aug	Sampling from Site 4	

Flounders remained in apparently healthy condition during transport (2.5 to 3 h), the exception being the poorer condition of Site 1 fish (first day samples) for which the bags were only aerated not oxygenated. On arrival in Oslo, fish were placed in an aquarium with circulating sea water at 10 °C. Crabs, mussels and winkles were kept cool and damp in insulated plastic bags during transport, and used for analysis immediately on arrival in Oslo. The numbers of animals sampled at each site are shown in Table 6; a timetable summarising the field sampling programme is given in Table 7.

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