Demersal and Benthic Communities in Howe Sound Basin and Their Responses to Dissolved Oxygen Deficiency

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ERRATA SHEET

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Caption for Fig. 1 should read as follows:

Fig. 1. Charts of Howe Sound showing stations for original solid waste survey (right inset) and stations for hydrography in the inner basin (left).

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ABSTRACT

Levings, C. D. 1980. Demersal and benthic communities in Howe Sound basin and their responses to dissolved oxygen deficiency. Can. Tech. Rep. Fish. Aquat. Sci. 951: 27 p.

Bottom waters (> 180 m) in Howe Sound, a fjord on the south coast of British Columbia, were almost completely devoid of dissolved oxygen (D.O.) during August to November 1977. D.O. levels were < 0.5 mg L^{-1}. A moderate incursion in November increased levels to about 3.0 mg L^{-1}, but values decreased again in summer 1978. A large volume of oxygenated water replaced this bottom water in February 1979, increasing D.O. values to about 6 mg L^{-1} throughout the whole water column.

A previous sampling program using trawls provided thorough baseline data on the structure of benthic communities immediately before the D.O. deficiency in 1977. Communities at deep stations behind the sill were dominated by decapod shrimps (*Spirontocaris* spp.), the gastropods *Neptunea phoeniceus*, and *Colus halli*, the heart urchin *Brisaster latifrons* and several fish species, especially the English sole *Parophrys vetulus*, the eelpout *Lycodes diapterus*, and the brown cat shark *Apristurus brunneus*. In August 1977, infauna and sedentary epifauna were killed over an area of approximately 24 km^2. During the periods of oxygen deficiency, shells and decomposing urchin tests dominated catches. Escape from the oxygen-deficient habitats and subsequent reoccupation after incursions appeared dependent on behaviour, tolerance and mode of reproduction of individual species.

Key words: Oxygen depletion, fjord, demersal fish, macrobenthos, mortality, colonization.

RÉSUMÉ

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D'août à novembre 1977, la teneur en oxygène dissous (O.D.) des eaux profondes (< 180 m) de la baie Howe, fiord situé sur la côte sud de la Colombie-Britannique, a été inférieure à 0,5 mg L^{-1}. En novembre, à la suite d'un brassage modéré des eaux, elle est montée à 3,0 mg L^{-1} environ, mais a chuté de nouveau à l'été de 1978. En février 1979, de fortes quantités d'eau oxygénée ayant remplacé les eaux profondes de la surface au fond, la teneur en O.D. est passée à 6 mg L^{-1}.

Au cours de chalutages antérieurs, on avait recueilli, immédiatement avant la déperdition d'oxygène de 1977, des données fondamentales sur la composition des communautés benthiques. Dans les stations profondes situées derrière le seuil, ces communautés se composaient principalement de crevettes (Spirontocaris spp.), des gastéropodes Neptunea phoeniceus et Colus halli, de l'oursin Brisaster latifrons, et de plusieurs espèces de poissons, notamment de la plie grand-père (Parophrys vetulus), de la lycode Lycodes diapterus, et de la roussette Apristurus brunneus. En août 1977, l'endofaune et l'épifaune furent détruites sur une superficie d'environ 24 km^2. Durant les périodes de désoxygénation, les prises renfermèrent surtout des coquilles et des oursins en état de décomposition. L'abandon des habitats déficients en oxygène et leur réoccupation après que l'eau fut réoxygénée, a semblé dépendre du comportement, de la tolérance et du mode de reproduction des différentes espèces.

Mots clés: perte d'oxygène, fiord, poisson démersal, macrobenthos, mortalité, colonisation.

INTRODUCTION

This report presents benthic biological observations related to dissolved oxygen (D.O.) conditions before, during and after 2 renewals of bottom water in the northern basin of Howe Sound on the southwest coast of British Columbia. This fjord is characterized by aperiodic renewals below the depth of the inner sill, and exchanges extend to the bottom waters of the basin possibly every 3 or 4 yr (Bell 1973). The biological work was conducted partly in conjunction with studies relating to ocean dumping in Howe Sound. Trawl surveys began in August 1976. A dramatic decline in benthic and epibenthic communities behind the sill was observed in August 1977, and this prompted an extension of surveys until a large exchange of water occurred in March 1979. Results are pertinent to several applied problems including ocean dumping and aquatic D.O. criteria. Basic data on fish and epibenthic organisms in British Columbia fjords are not available, although Ellis (1970) and Bernard (1979) have reported on infaunal communities in the Strait of Georgia, which connects with Howe Sound.

STUDY AREA

The southern portion of Howe Sound is actually an embayment of the Strait of Georgia, separated from its major basin by a relatively deep sill (110 to 200 m). A much shallower sill (30-70 m) separates this embayment from an inner basin, which has a maximum depth of 298 m (Fig. 1). Sediments on the floor of Howe Sound vary along its axis. Outside the inner sill, sediments are very fine silts (median grain size about 5 μm), characterized by high water content (> 80%). Inside the sill, sediments are also mud or silt (median grain size about 20 μm) except off Britannia (Fig. 1) where mine tailings (median grain size 80 μm) are mixed with muds (Syvitski 1978).

Physical oceanographic data from Howe Sound have been reported by a number of authors including Pickard (1961, 1975), Bell (1973) and Buckley (1977). Bell (1973) provided a detailed review of the processes involved in bottom water renewal into the deep basin of Howe Sound. The majority of the surface fresh water in the Sound is contributed by the Squamish River (mean annual flow rate 242 $m^3\ s^{-1}$), which has maximum runoff during spring and autumn. Seasonal changes in temperature and salinity characteristics of the bottom water behind the inner sill are slight compared to surface waters. At 200 m salinity ranged from approximately 30.1 to 30.6‰ during 2 1/2 yr of observation in our work (Station H2). At a similar location and depth, temperature varied from about 8.2 to 8.5°C over the period 1971-1973 (Bell 1973).

SAMPLING

Stations for trawling and hydrography were aligned along the axis of Howe Sound as shown in Fig. 1. Stations H1 (235 m), H2 (290 m), H3 (260 m), and H4 (180 m) were among the trawl stations established in the original solid waste survey which began in August 1976. Sampling at Station H4A (125 m), in the shallower north end of the Sound, began in August 1977, shortly after we observed the marked change in communities at the deeper stations. Station H1, located south of the sill at Porteau, was "control" for the deeper stations, as D.O. depletion did not occur outside the sill.

Sampling for oceanographic parameters (prefix X) occurred at stations matching the above trawl locations. Fortuitiously, hydrographic sampling near Station H2 had been conducted bimonthly since August 1976, and these data were kindly made available by A. J. Dodimead. Water samples were obtained with Nansen bottles, and D.O. was determined using the modified Winkler titration method outlined in Strickland and Parsons (1972).

Biological samples were obtained using a small otter trawl (6 m throat) with 3.2 cm mesh body web and 1.3 cm mesh codend liner. Except for one survey in October 1977, all samples were obtained from C.S.S. VECTOR (39 m, 640 hp). The October cruise was on R/V CALIGUS (16 m, 155 hp). Generally, 3 replicate trawls were obtained at each station. The trawl was normally fished with a 3:1 scope for 10 min duration (vessel speed approximately 2 knots, 0.5 to 0.1 km of bottom covered), once the full scope was paid out. The catch was rough sorted while washing through a 5 mm mesh screen.

We were able to use shipboard balances for weight determinations because wave action and ship motion was usually reduced in the enclosed waters of Howe Sound. Individual taxa were weighed using either a Ohaus 2 kg trip balance or a Mettler PL3000 electrobalance. Heavier specimens were weighed using an Accu-weigh Model BD-50-M pan balance.

STATISTICAL METHODS

Differences in community composition throughout time at individual stations were contrasted using numerical catch data (number per trawl) for each taxa. The similarity index used was the Euclidean distance measure, and times were sorted using centroid analysis. The computer program used was the "Cluster" routine documented in Fox and Guire (1976).

WATER CHARACTERISTICS

Dissolved oxygen features were analyzed by plotting D.O. changes with time and on axial sections of Howe Sound. Data are most extensive from a station located inside the sill, near trawl station H2 (D.O. station X4).

At 250 m, D.O. values declined from approximately 3.0 mg L^{-1} in August 1976 to about 0.5 mg L^{-1} in August to October 1977 (Fig. 2). Renewal of deep water did not occur in winter 1976-1977. An incursion did occur in November 1977, but D.O. values again declined during 1978 so that by November 1978 values were below 0.5 mg L^{-1}. Sometime during the period December 1978 to early March 1979 a large incursion of oxygen-rich water occurred, so that D.O. values at almost all depths increased to over 6.0 mg L^{-1}.

D.O. values outside the inner sill (D.O. Station X1) were always above 4.0 mg L^{-1} (Fig. 3). Oxygen deficient bottom waters (e.g. < 0.5 mg L^{-1}) extended from behind the sill (Station X4) to Station X11 at Watts Point, and were mainly confined to depths of over 180 m. There was no significant difference between D.O. values at 250 m from Stations X4 and X8, so data after August 1977 were combined (Fig. 4). Approximately 24 km^2 of benthic habitats were affected by the prolonged D.O. depletion. Data at Station X13 (120 m), off Darrell Bay, were obtained only after August 1977. D.O. values in bottom waters at this location (100 m) were usually greater than 2.0 mg L^{-1} (Fig. 5). Longitudinal sections of D.O. for each sampling time show patterns which complement the above results, and sections for salinity show patterns of water displacement which match the changes in D.O. described above. As Bell (1973) suggested, salinity can be used to trace patterns of water replacement in Howe Sound. Tabulated data for D.O., salinity, and plots of longitudinal sections for D.O. are presented elsewhere (Levings and McDaniel 1980).

BIOLOGICAL RESULTS

Species composition, relative abundance, biomass and other characteristics of the catches at the station inside the sill changed as the study progressed. Most of the organisms at all the stations were cnidarians, gastropods, bivalves, polychaetes, decapods, echinoderms and fish. Taxonomic composition and abundance at H1 was relatively constant (Fig. 3), and about 53 taxa were obtained at this station, 24% of which were fish. At Station H2, 38 taxa were obtained, 26% of which were fish. Biomass of fish decreased with depth when stations outside the sill were compared and ranged from approximately 2 kg to 0.1 kg wet weight per trawl (Fig. 6). Stations inside the sill were more difficult to compare because of the influence of the oxygen deficiency. Tabulated data for all samples are presented elsewhere (McDaniel et al. 1978; Levings and McDaniel 1980).

Table 1 lists the most frequent (encountered in > 70% of catches) taxa at the various stations. Several numerically dominant taxa at H1 were infrequent at other stations, for example the holothurian Chiridota sp., the asteroids Ctenodiscus crispatus and Pseudarchaster paalle, and the poriferan Iophon pattersoni. Most of the other frequently occurring taxa were obtained at all the other stations. Fish taxa were most frequent at Station H4A. Lycodes diapterus was the only fish specieswhich occurred frequently both inside and outside the inner sill.

Changes in abundance and diversity of invertebrates and fishes were most striking at the deep stations inside the inner sill (H2 and H3). Catches of invertebrates and fish had decreased dramatically by August 1977 (Fig. 4). Fish abundance decreased gradually over February to August 1977. Catches of the heart urchin Brisaster latifrons actually increased over the period February to May before declining in August. At Station H2 B. latifrons usually accounted for > 50% of catches but no living specimens were observed in 1977. Other invertebrates such as the gastropods Neptunea pheonicius and Colus halli were still in the process of decomposing so samples were very odorous.

After renewal of bottom water in late autumn 1977 fish abundance increased to moderate levels as did invertebrate catches. When D.O. levels again decreased in summer 1978, fish catches were again depressed until the major renewal occurred in late winter 1979. Invertebrate catches increased dramatically after renewal in late 1977. However, species composition was very different and living sedentary invertebrates were not observed. After August 1977, the only evidence of the large populations of the echinoid and gastropods was shell without tissue. B. latifrons gradually decomposed so that by March 1979 individual tests were not recognizable. Invertebrates in catches were dominated by juveniles of the shrimps Spirontocaris spp. and the galatheid crab Munida quadrispina.

Station H4 showed the highest variability in catches of fish (1 to 100 per trawl) and invertebrates (30-8000 per trawl), although the number of taxa was relatively consistent (approximately 10). Patterns in catches could not be easily correlated to seasonal differences or shifts in bottom D.O. values. The extreme variation in catches may be partially explained by navigation problems and/or bottom sediment patchiness. A submarine cable is close to this station, so replicate trawling at this site is difficult for navigation reasons. An ocean dumpsite, where gravel, sand, and wood debris is deposited, is also close by, and sediments are very heterogeneous.

At Station H4A, where sampling began shortly after D.O. deficiency, communities varied mainly with season (Fig. 5). Catches of fish were consistently high (usually about 50 to 150 per trawl) and were often dominated by zoarcids (Lycodes diapterus, Lycodopsis pacifica) and pleuronectids (Parophrys vetulus, Lyopsetta exilis). Abundance of both fish and invertebrates was generally lower in the winter season.

STATISTICAL RESULTS

Cluster analyses on times showed similar patterns to those observed with abundance and taxa data. Dendrograms generated from Station H1 show that community structure at most of the sampling times (9 out of 14) were similar at above the 0.5 level (Fig. 1), so that the data set was relatively homogeneous. Analyses of data from Station H2 (Fig. 7) show clearly that communities changed dramatically after August 1977. Samples obtained before and after that date separated sharply in the dendrogram analysis. Cluster analyses of data from Station H3 also showed differences related to the declining D.O. levels. Data from August and November 1976 linked together at a high similarity level, but February and May 1977 were apparently quite dissimilar. This may have reflected the withdrawal of most of the fish species from this habitat. The dendrograms also reflect the "temporary recovery" of the communities from D. O. deficiency. Data from December 1977, January and February 1978 and March 1979 were linked at both Stations H2 and H3 (Fig. 7).

DISCUSSION

A. FACTORS IMPLICATED IN D.O. DEPLETION

An anomalously mild winter occurred in 1976, and outbreaks ("Squamish winds") of cold air from the interior of British Columbia were infrequent in the winter of 1975 and 1976 (Table 2). These winds, together with runoff conditions and availability of dense water outside the sill, are thought to be major determinants in flushing Howe Sound basin (Bell 1973). The data suggest that the oxygen depletion observed in this study was a natural event. No unusually large inputs of organic material originating from solid waste disposal occurred at the time our observations were made. Ocean disposal (about 25,000 m^3 per year) of solid wastes, usually dredged material mixed with wood wastes, is conducted near Watts Point (Fig. 1). A 600 tonnes per day pulp mill at Woodfibre discharges fibrous wastes in surface layers.

Although a quantitative assessment or budget of the various sources and sinks for D.O. in Howe Sound basin is beyond the scope of this paper, such an exercise would be useful to help determine if industrial effects such as ocean dumping are impinging on the natural sequences of oxygen depletion. Studies at Alberni Inlet, on the west coast of Vancouver Island (e.g. Macdonald 1979) suggested that bacterial and zooplankton respiration and decomposition of phytodetritus probably accounted for more D.O. depletion than disposal of dredge spoil. In certain Norwegian fjords (e.g. Oslofjord, Beyer 1968) sewage disposal had a very significant effect on bottom D.O. levels. Steimle and Sindermann (1978) have recently published a review article on the topic of natural depletion in dissolved oxygen, with special reference to the New York Bight. At that location a natural depletion of D.O. in 1976 was responsible for the death of benthos over about 14,000 km^2. An exceptionally large "bloom" of the dinoflagellate Ceratium tropos was implicated in the New York Bight study.

B. FAUNISTIC COMPARISONS

Even before D.O. deficiency became a feature of habitats during our study, it was clear that the deeper parts of Howe Sound were characterized by different fish and invertebrate communities compared to shallower habitats. In general fish abundance and diversity were reduced in the basin habitats (Fig. 6). Levings (1973) reported 37 species of fish in 75 trawls in shallow water (10 to 50 m) of outer Burrard Inlet, near the mouth of Howe Sound.

At depths over 200 m in the present study only 19 species were taken in about the same number of trawls. The relative lack of abundant bottom fish in deeper British Columbia inlets is confirmed by commercial fishing patterns . Other than blackcod (Anoplopoma fimbria) fisheries in Jervis Inlet and Fitz Hugh Sound there appear to be no other demersal fisheries in the fjords. There are, however, significant catches of prawns (Pandalus platyceros) in the deep inlets, including Howe Sound (outside the inner sill). The decreases in fish abundance may be related to changes in food supply, as Pearson (1980) showed a negative correlation between invertebrate biomass and depth when data from several fjords were compiled.

Because a number of review papers (Davis 1975; Steimle and Sindermann 1978) have recently appeared on the topic of low oxygen environments, detailed comparison with other study areas will not be attempted. There are few comparable studies from the northeast Pacific. However, judging from the unpublished trawl data kindly provided by A. J. Mearns (Mearns et al. 1978), the deep basins (549-915 m) off southern California (Santa Monica-Santa Barbara basins) are characterized by fish and invertebrate communities which have some similarities to those from Howe Sound. The bottom waters in these basins are known to be oxygen deficient, as D.O. values as low as 0.8 mg L^{-1} were recorded by Mearns and Word (1975). Taxa in common with this study include the brown cat shark (A. brunneus), dover sole (Microstomus pacificus), sablefish (Anoplopoma fimbria), and the shrimp Spirontocaris spp. Two species of thornyheads (Sebastolobus spp.) and a rattail (Nezumia stelgidolepis) were the most abundant fish in the California basins but neither were recorded from Howe Sound. A heart urchin (Brisaster pacificus), related to our Brisaster latifrons, was abundant. Unfortunately, time series data from the California habitats are not available for comparison.

C. BIOLOGICAL RESPONSES TO D.O. DEPLETION AND RECOVERY

Sedentary adult organisms such as the heart urchin Brisaster latifrons and the bivalve Macoma nasuta could not escape the D.O. depletion and died. Before death, however, catches of the heart urchin increased as D.O. levels decreased (Fig. 4). It is possible this species was migrating to shallower depths in the sediment in an attempt to escape the decreased oxygen levels. The urchins would become more available to our trawl if they were closer to the sediment surface. Recent work in Puget Sound suggests this species can move vertically in sediments to 25 cm (Nichols, personal communication). A related echinoderm, the asteroid Ctenodiscus crispatus, was shown to increase activity of the epiproctal cone (ventilation chamber) in laboratory conditions of reduced D.O. (Shick 1976). Certain slow-moving fish species for example the brown cat shark Apristurus brunneus may also have suffered direct mortality as carcasses of this species were obtained in trawls after the initial D.O. depletion. Fish such as the eelpout Lycodes diapterus presumably escaped from the low D.O. areas by moving into shallow waters (see below). Certain crustacea such as the decapod shrimp Spirontocaris spp. and the galatheid crab Munida quadrispina appeared able to exploit the oxygen deficient environments to some extent. It is possible these mobile species migrated, perhaps on a daily basis, into upper water layers characterized by higher values of D.O.

Patterns of recovery following D.O. renewal of various species also reflected behaviour and reproductive patterns. Spirontocaris spp. presumably moved back into the deep basin habitats from shallow regions of the Sound which afforded refuge from the prolonged low D.O. levels. Fish populations could also recruit from refuges if behaviour and reproductive mechanisms permitted. Species without pelagic eggs (e.g. L. diapterus and A. brunneus) must rely on reproductive recruitment from populations behind the sill whereas those with pelagic eggs (e.g. the lemon sole Parophyrs vetulus and the slender sole Lyopsetta exilis) could re-establish populations from habitats inside and outside the sill. Many species of infaunal invertebrates for example the heart urchin Brisaster latifrons also recruit with pelagic larvae (Gibbs 1963).

The frequency of mass mortality events and patterns of restoration are of considerable interest, as there are no data on this topic from the northeast Pacific. Based on Gibbs' (1963) age-length data and a comparison of about 100 measurements of B. latifrons obtained in February 1977, the average age of urchins in Howe Sound Basin (Station H3) was about 1 yr. Those outside the inner sill (Station H1) were about 3 yr old. If the urchins in the former location are recruited from outside the sill, these data suggest the B. latifrons population is annihilated every 3 yr, consistent with Bell's (1973) conclusions about the frequency of bottom water renewal in Howe Sound basin.

D. RELATIONSHIPS TO D.O. CRITERIA

Based mainly on laboratory results, several authors (e.g. Davis 1975) have attempted to establish "limits" or "criteria" for the oxygen tolerance of marine organisms. Our information from Howe Sound Basin provides further data on these criteria, with a field perspective.

Fish species, for example, the lemon sole P. vetulus and the eelpout L. diapterus, provide an example of how data from the field are important (Fig. 8). P. vetulus catches gradually declined over the period August 1976 to May 1977, when D.O. values decreased to $\lessapprox 1.0$ mg L^{-1}, and this species was never taken again at the deeper stations. In contrast, L. diapterus catches shifted directly with D.O. values, re-occupying habitats when values increased over 1.0 mg L^{-1}. Tiews (1970) reported that similar values for D.O. (1.5-2 $m\ell^{-1}$) stimulated the movement of Baltic cod (Gadus morhua) from the bottom to pelagic habitats. Interestingly, P. vetulus is a "small-mouthed" flounder and feeds on infauna whereas L. diapterus can feed on epibenthos in the water column near the bottom. Infaunal organisms were of course killed by the D.O. deficiency and it is possible P. vetulus was restricted because of an inadequate food source. The Baltic cod studied by Tiews (1970) is also a facultative benthic feeder. Two decapod crustaceans which displayed very similar patterns were the pink shrimp Pandalus borealis and the shrimp Spirontocaris spp. Analyses of other species are beyond the scope of this paper but detailed data on catch composition are presented elsewhere (McDaniel et al. 1978; Levings et al. 1980).

Since laboratory experiments generally do not allow for differences in "external" factors such as food supply, it may be advisable to verify or refine oxygen criteria levels derived with field data (Davis 1975).

Analyses of the catch patterns of all species encountered in Howe Sound Basin will not be attempted here but persons interested in certain taxa could use our tabulated data (McDaniel et al. 1978) to help formulate criteria. Howe Sound Basin, characterized by varying and "semi-predictable" D.O. levels, provides an ideal field laboratory to explore such relationships. Work on shallower basins, also characterized by low and fluctuating D.O. levels (e.g. Nitinat Lake [Vancouver Island], Minette Bay [Kitimat Arm, mainland coast of British Columbia; Pickard 1961]) but accessible by SCUBA would be even more fruitful as behavioural observations could be made in situ.

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Table 1. Taxa occurring in 70% of greater of trawl catches at stations indicated. Data from Station H2 and H3 are from samples previous to August 1977, all others from period August 1976 to December 1977.

H1	H2	H3	H4	H4A
Iophon pattersoni[1]	Colus halli[3]	Neptunea phoeniceus[3]	Neptunea phoeniceus[3]	Neptunea phoeniceus[3]
Actinostola spp.[2]	Macoma nasuta[4]	Spirontocaris spp.[6]	Colus halli[3]	Colus halli[3]
Colus halli[3]	Yoldia thraciaeformis[4]	Munida quadrispina[7]	Spirontocaris spp.[6]	Pandalus borealis[6]
Neptunea phoeniceus[3]	Spirontocaris spp.[6]	Brisaster latifrons[8]	Munida quadrispina[7]	Spirontocaris spp.[6]
Natica russa[3]	Munida quadrispina[7]		Brisaster latifrons[8]	Crangon communis[6]
Fusitriton oregonensis[3]	Brisaster latifrons[8]	Lycodes diapterus[11]	Molpadia intermedia[10]	
Yoldia thraciaeformis[4]		Lyopsetta exilis[11]		Lycodes diapterus[11]
Macoma nasuta[4]		Parophrys vetulus[11]	Lycodes diapterus[11]	Lycodopsis pacifica[11]
Nucula tenuis[4]		Microstomus pacificus[11]	Lumpenella longirostris[11]	Bathyagonus nigripinnis[11]
Sternapsis fossor[5]			Parophrys vetulus[11]	Microstomus pacificus[11]
Pandalus borealis[6]			Hydrolagus colliei[11]	Parophrys vetulus[11]
Pandalopsis dispar[6]			Lyopsetta exilis[11]	Theragra chalcogramma[11]
Spirontocaris spp.[6]				Merluccius productus[11]
Munida quadrispina[7]				
Brisaster latifrons[8]				
Ctenodiscus crispatus[9]				
Pseudarchaster parelli[9]				
Chiridota sp.[10]				
Molpadia intermedia[10]				
Lycodes diapterus[11]				
Dasycottus setiger[11]				

[1] = Porifera; [2] = Cnidaria; [3] = Gastropoda; [4] = Bivalvia; [5] = Polychaeta; [6] = Decapoda Natantia; [7] = Decapoda Reptantia; [8] = Echinoidea; [9] = Asteroidea; [10] = Holothuroidea; [11] = Pisces.

Table 2. Meterological data for January from stations in Howe Sound. Hours of wind data are summary of "outflow" (northeast) winds with duration of > 12 h and strength > 20 mph. Wind data from Squamish, temperature data from Gibsons (south end of Howe Sound), courtesy of Atmospheric Environment Service.

	January								
	1971	1972	1973	1974	1975	1976	1977	1978	1979
Hours of wind	79	69	13	70	0	0	n.d.	n.d.	n.d.
Monthly mean temperature (°C)	2.8	0.6	2.8	2.8	2.2	3.9	2.8	3.3	1.3

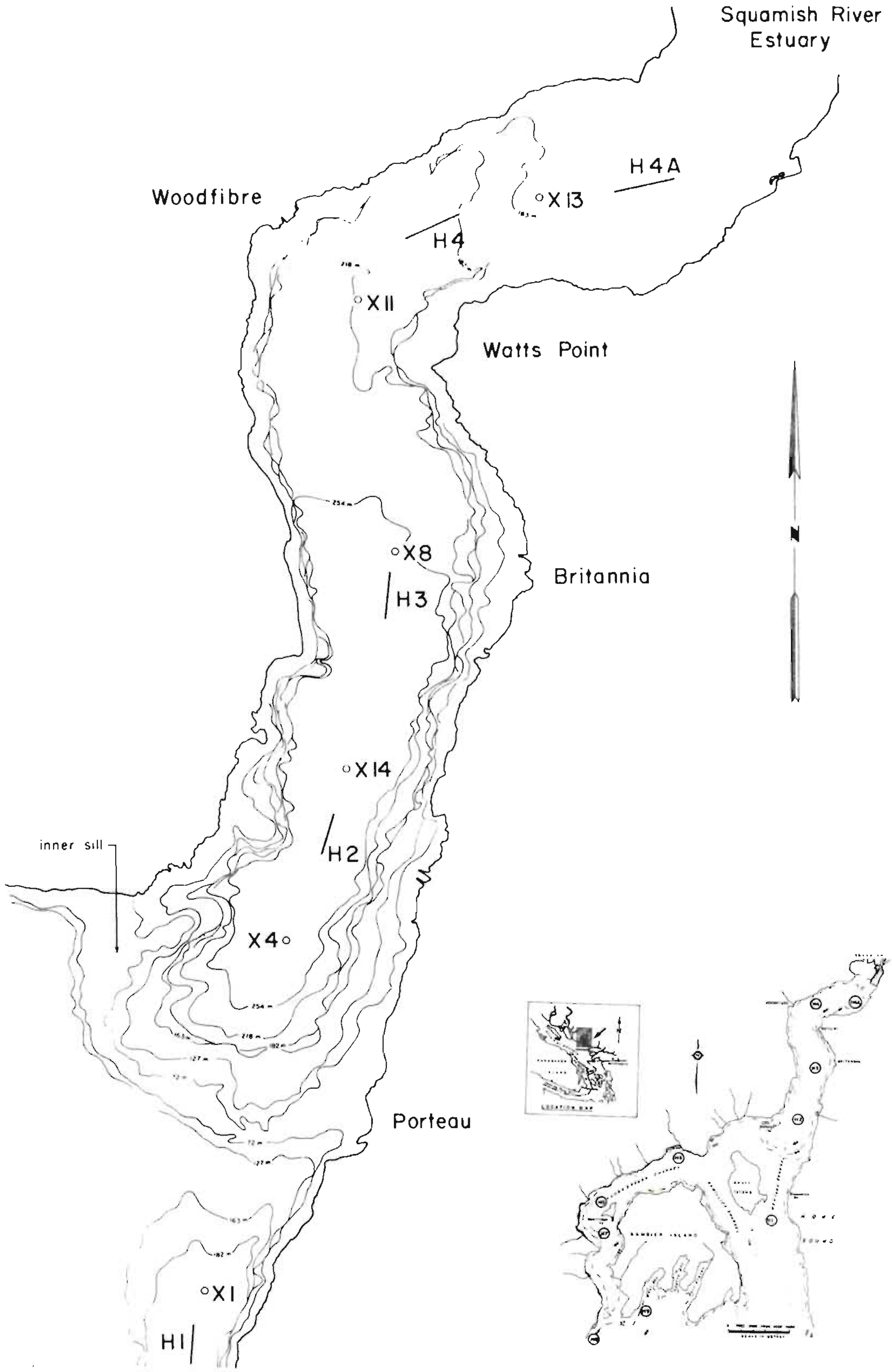

Fig. 1. Chart of Howe Sound showing stations for original solid waste survey (left panel) and stations for hydrography in the inner basin (right panel).

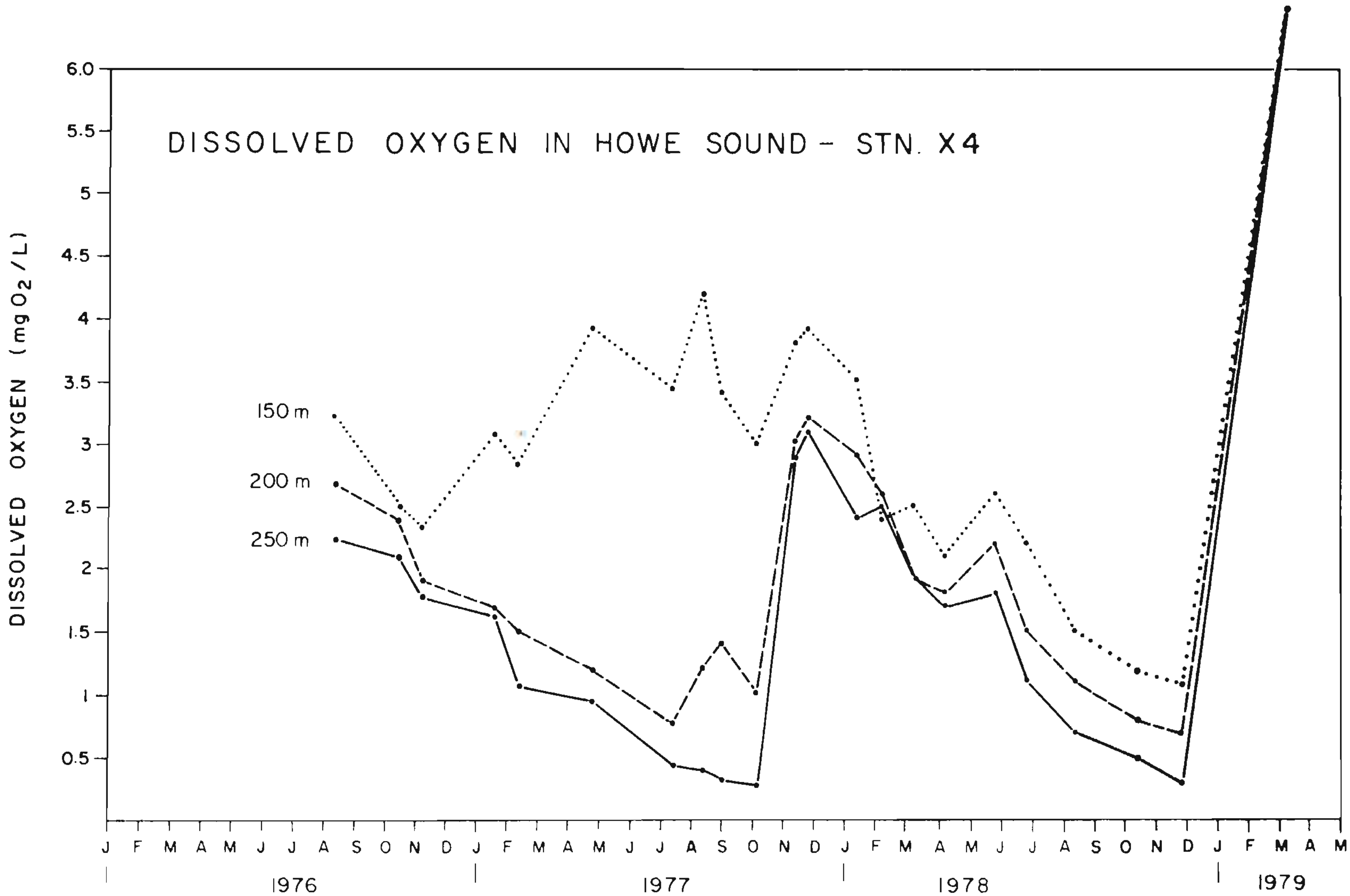

Fig. 2. Temporal changes (1976 to 1979) in dissolved oxygen (mg L^{-1}) at trawl station H2 (close to hydrographic station X4) in the inner basin of Howe Sound.

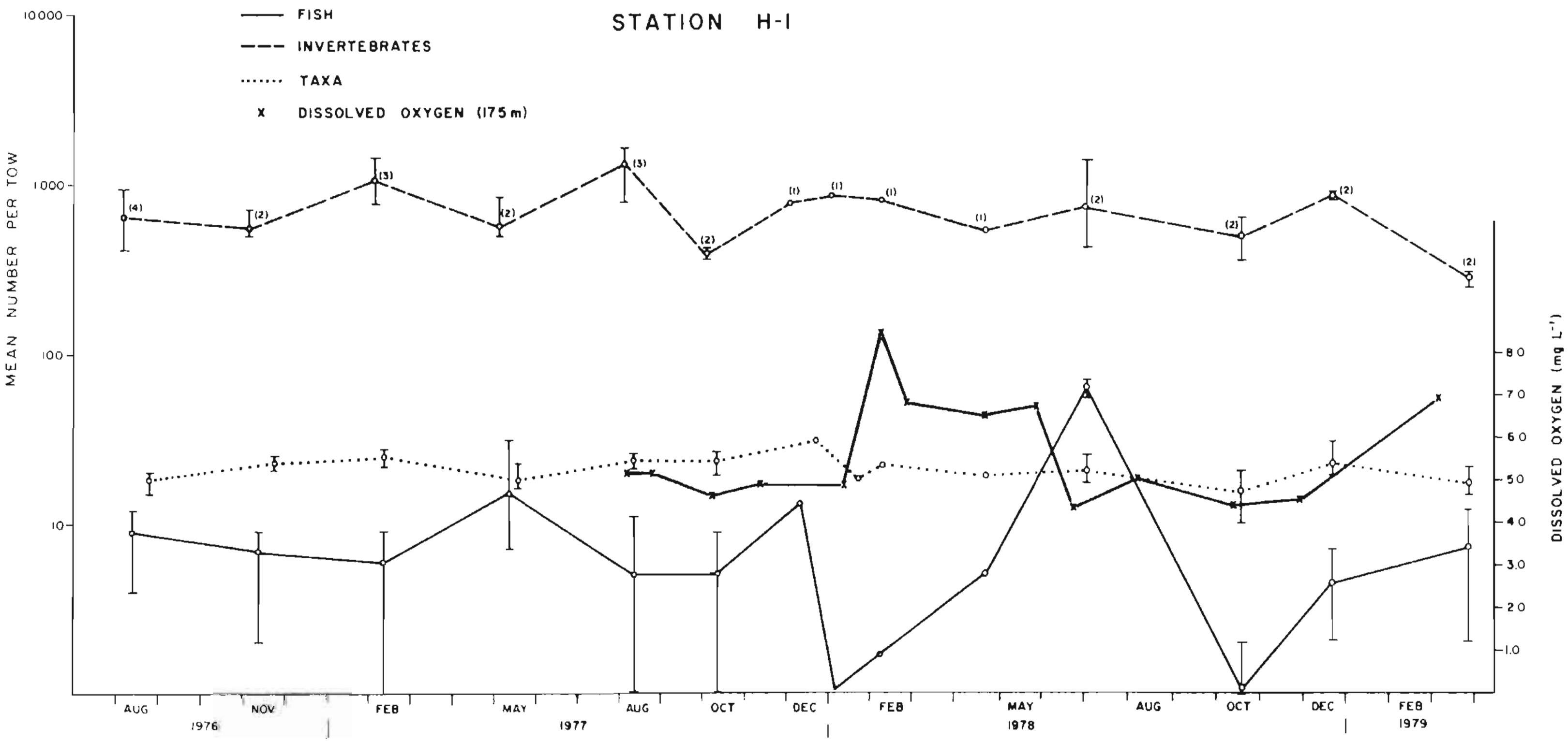

Fig. 3. Temporal changes (1976 to 1979) in number of taxa, number of fish, number of invertebrates, and dissolved oxygen (175 m) at station H1 (D.O. station X1), outside the inner sill of Howe Sound. Mean and ranges are shown for faunal data, and number of samples is shown beside data points.

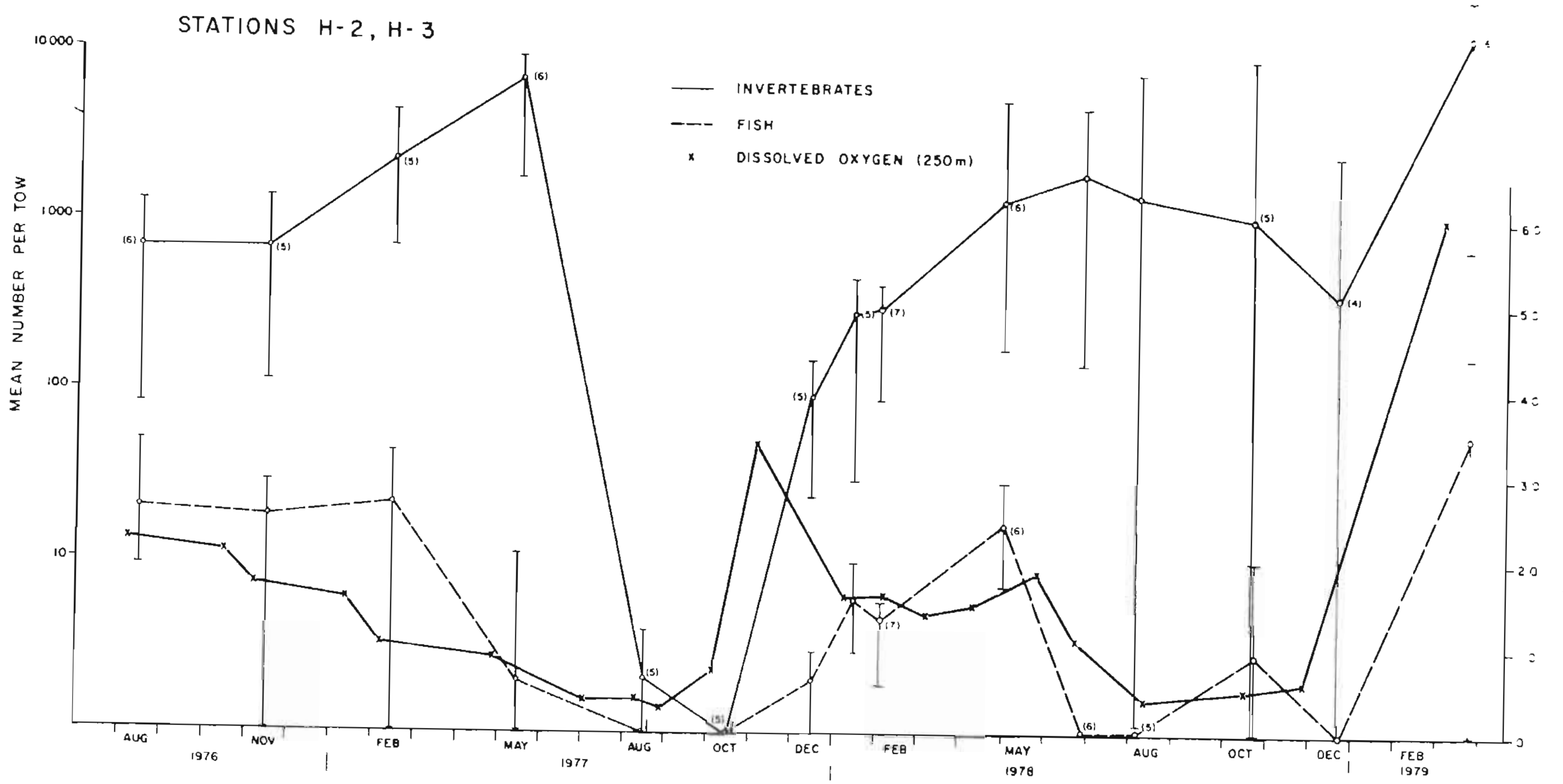

Fig. 4. Temporal changes (1976 to 1979) in number of taxa, number of fish, number of invertebrates, and dissolved oxygen (D.O.) (250 m) at stations H2, H3 (combined data) inside the inner sill of Howe Sound. Mean and ranges are shown for faunal data and number of samples is shown beside data points. D.O. data from August 1976 to August 1977 are from D.O. Station X4 only; subsequent data incorporates data from hydrography stations X4 and X8.

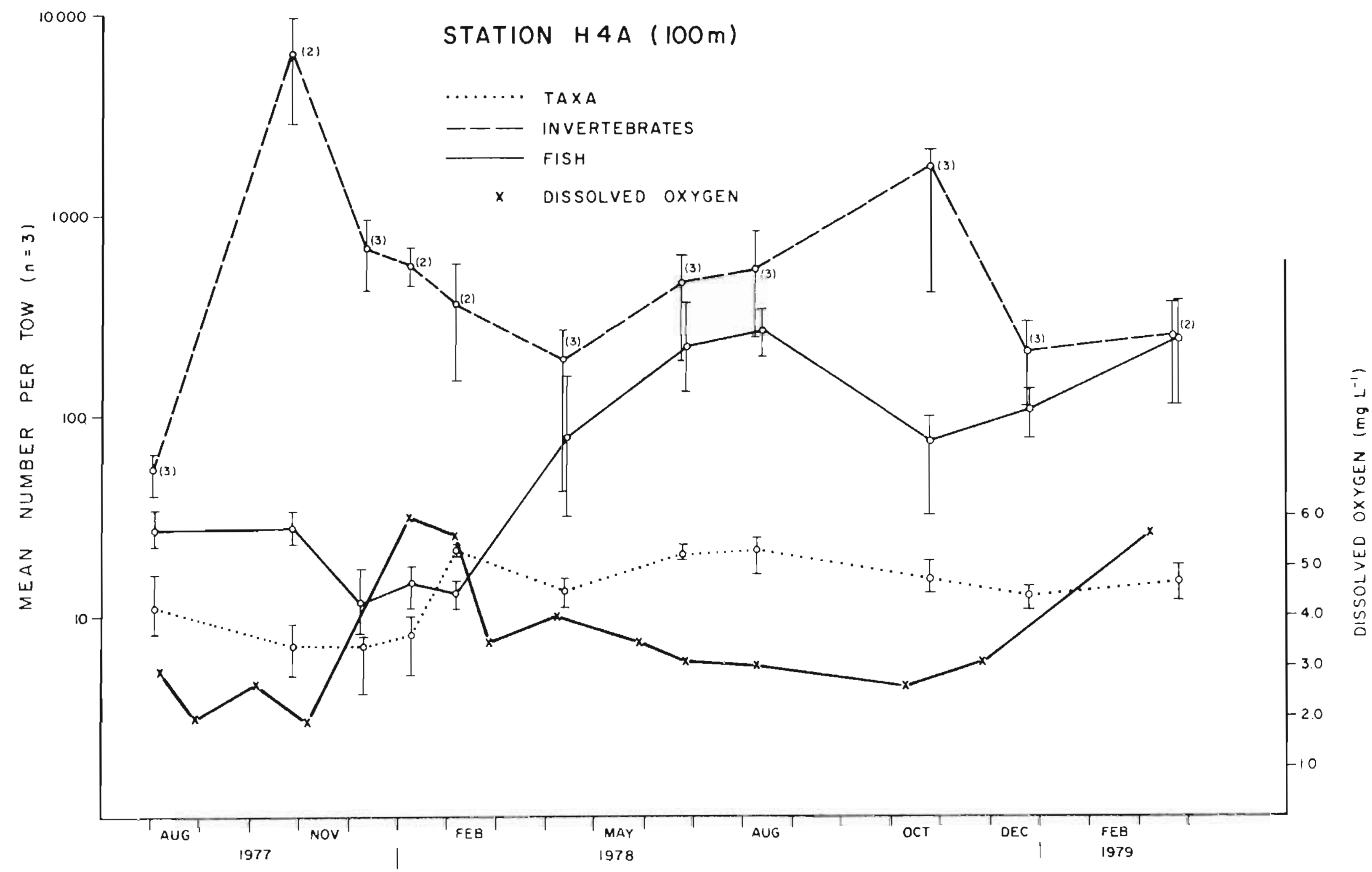

Fig. 5. Temporal changes (1977 to 1979) in number of taxa, number of fish, number of invertebrates, and dissolved oxygen (100 m) at station H4A, (D.O. Station X13) close to Squamish estuary at the head of Howe Sound. Mean and ranges are shown for faunal data and number of samples is shown beside data points.

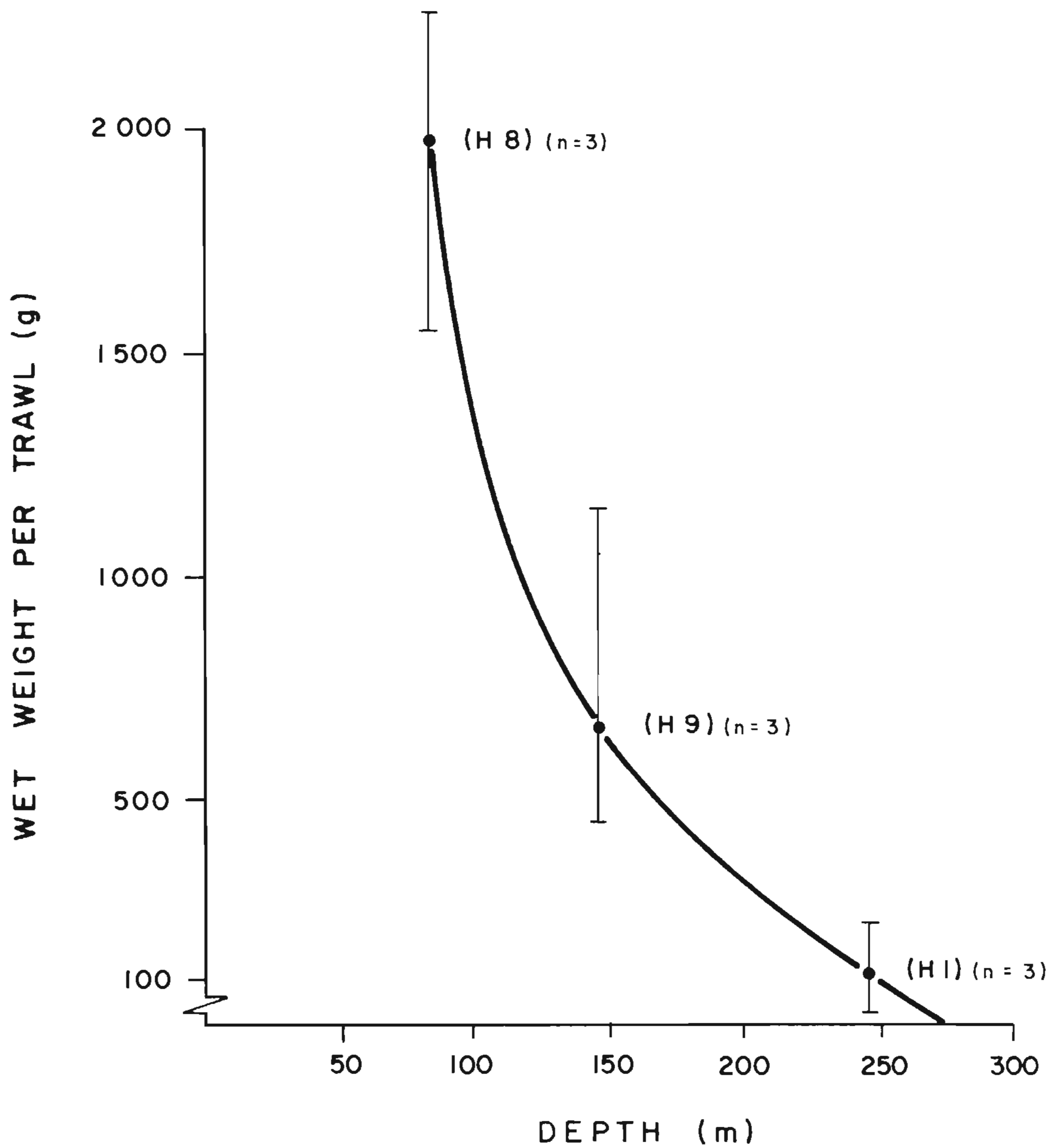

Fig. 6. Relationship between depth and biomass (wet weight) of fish per trawl from stations outside the inner sill of Howe Sound. Station numbers and number of samples are shown beside data points. Line fitted by eye.

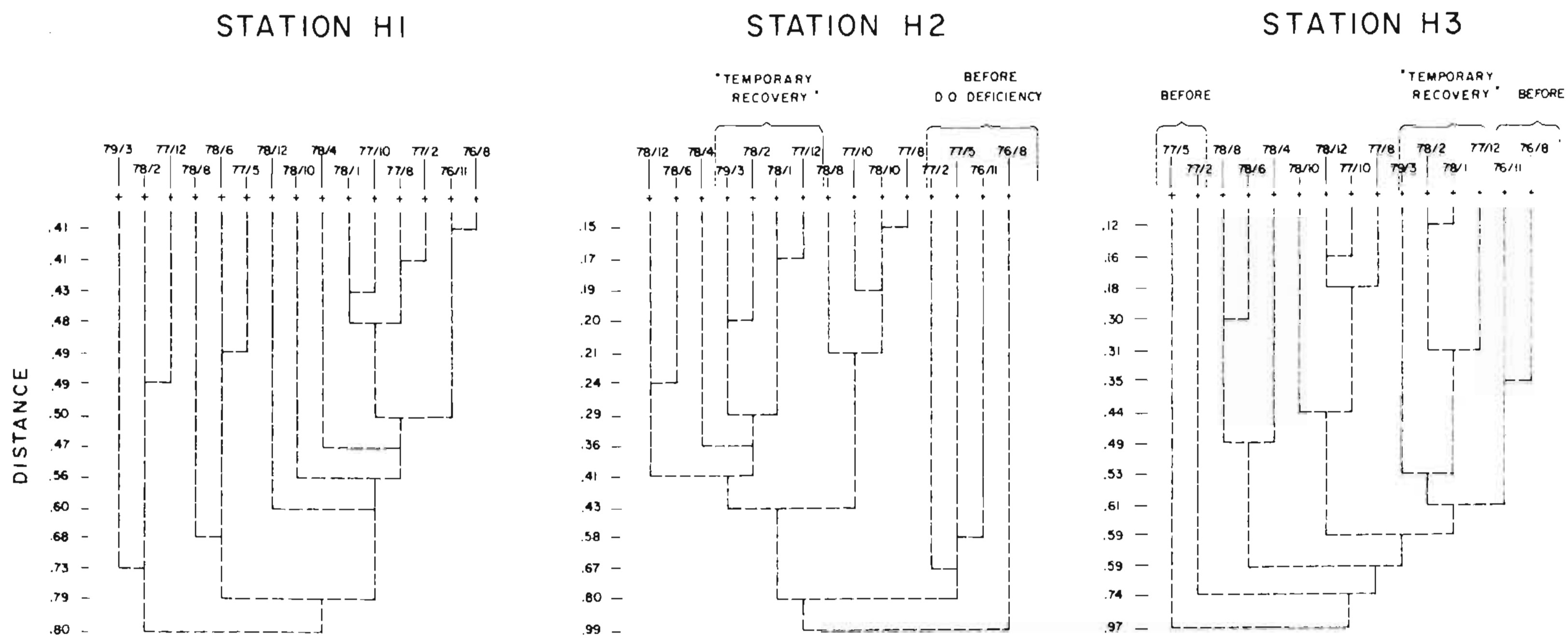

Fig. 7. Dendrograms showing similarity levels of trawl catches through time at stations south (H1) and north of the inner sill (H2, H3) of Howe Sound. The similarity measure used was euclidean distance with centroid sorting. Data on ordinates indicate distance between the clusters being joined at a particular step.

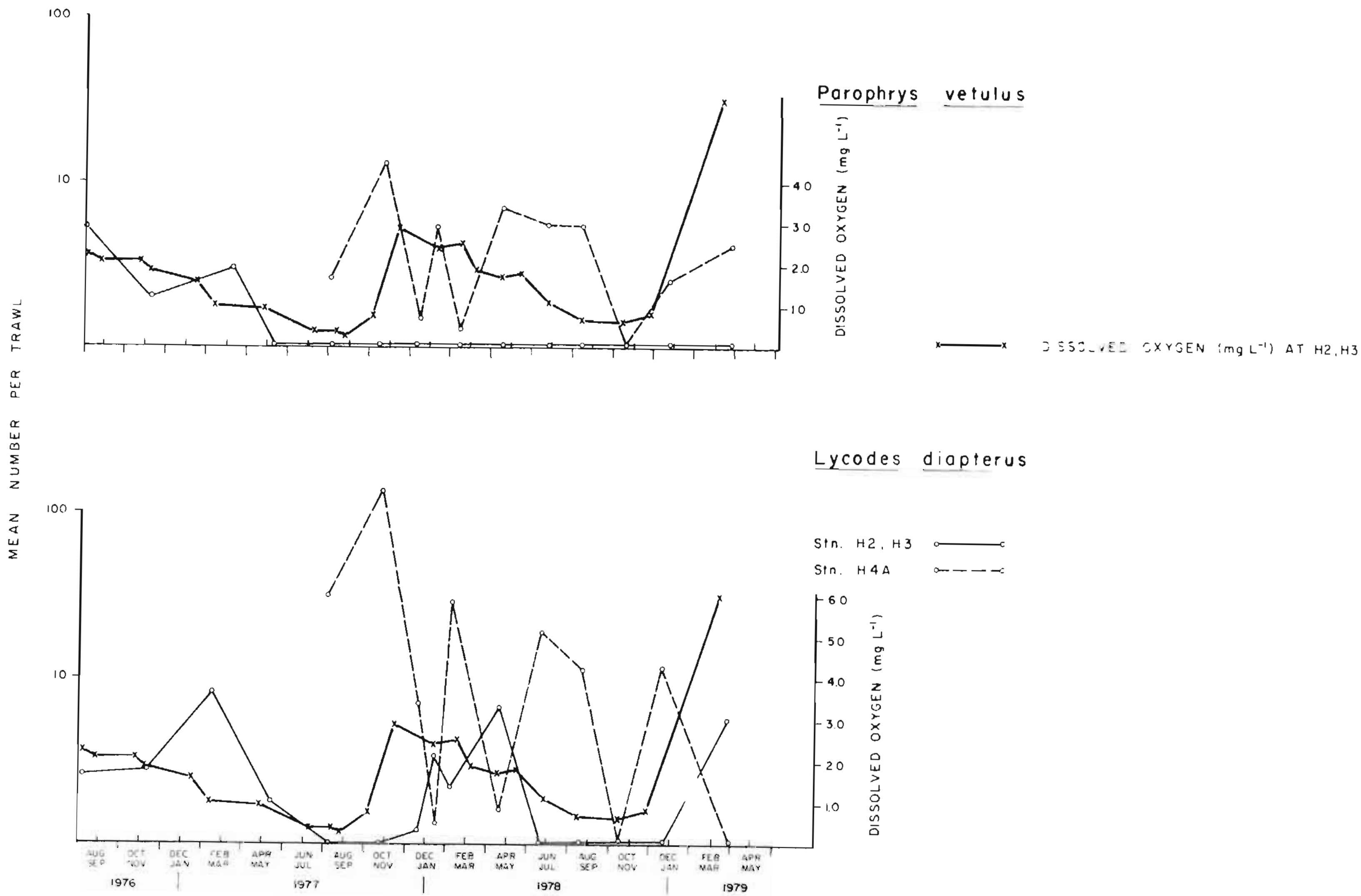

Fig. 8. Temporal changes (1976 to 1979) in number of lemon sole *(P. vetulus)* and blackfinned eel pout *(L. diapterus)* at stations H2, H3 (combined data) inside the inner sill of Howe Sound and dissolved oxygen at 250 m (D.O. Stations X4 and X8; data combined).