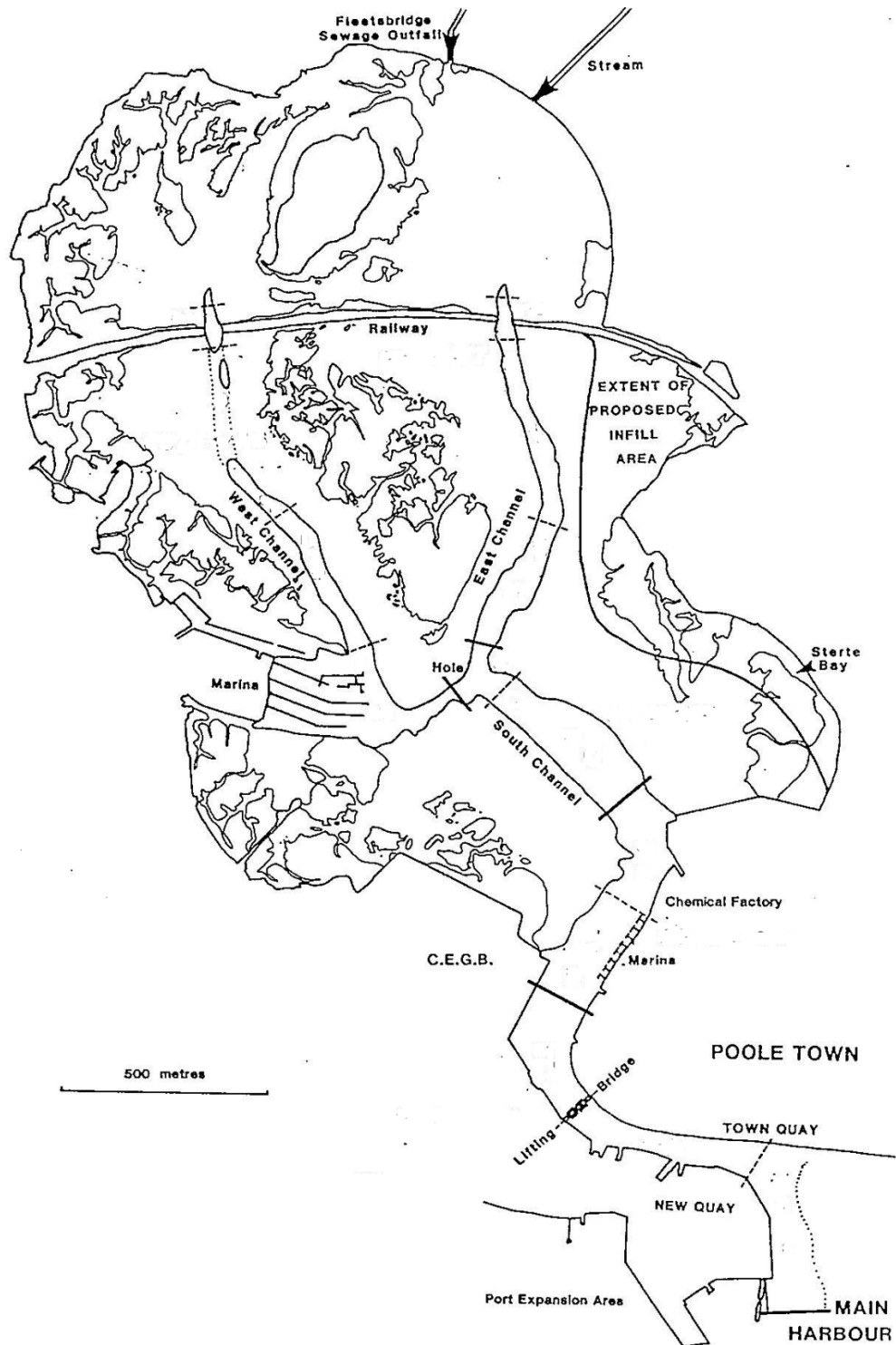


INVESTIGATION OF THE SUBTIDAL ECOLOGY OF HOLES BAY

POOLE HARBOUR

Report to Nature Conservancy Council. March 1983



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ABBREVIATIONS

D.C.C.	Dorset County Council.
M.A.F.F.	Ministry of Agriculture, Fisheries and Food.
N.C.C.	Nature Conservancy Council.
P.B.C.	Poole Borough Council.
P.H.C.	Poole Harbour Commissioners.
S.S.D.F.C.	Southern Sea District Fisheries Committee.
W.W.A.	Wessex Water Authority.

1) INTRODUCTION.

Poole Harbour is a major brackish-water system within the eastern basin of the English Channel, on the central southern coast of England.

The Harbour has been a centre of human activity since Roman times and before. Early developments centred on its use as a port and oyster fishery. These activities continue, and have been supplemented by development of the Harbour as a major yachting centre, a focal point for recreation and tourism, and within the expanding conurbation on its northern shores, there is a growing industrial base. Much of the undeveloped southern shores of the Harbour are embodied within nature reserves. However, substantial oil reserves, recently discovered beneath these shores, are currently being exploited.

Some of these developments have stressed the natural environment in various ways, the most evident being a substantial

reduction in area of the northern part of the Harbour over the last century, brought about by a succession of infilling programmes related to development of the Poole conurbation. Pollution problems have also arisen, particularly in the area of Poole.

A working party of ecologists investigating various aspects of the Harbour, has been established under the convenership of the Nature Conservancy Council.

In view of the decision to undertake another major infilling programme in the Poole area, to carry a road - route 9 - (in progress, February 1983), with the option of further infilling to support a road bridge - route Y - the relevant authorities decided to commission an ecological evaluation of the affected area - Holes Bay - in order to obtain an assessment of the ecological consequences of these and others infilling programmes.

This report describes the results and conclusions of a baseline survey and evaluation of the ecology of the subtidal channel system within Holes Bay. This covers both the environmental conditions as of now, i.e., the consequences of natural and human processes; and the communities of marine organisms which currently inhabit the system.

## 2) STATE OF A MARINE SYSTEM ACCORDING TO ITS CARRYING CAPACITY.

The communities of marine organisms - algae (seaweeds), invertebrates (e.g., barnacles; shellfish such as oysters, cockles and crabs) and true fish - colonizing any subtidal marine habitat, are the product of natural and human influences which together determine the physical and chemical conditions of the habitat. The 'carrying capacity' of a habitat, is the totality of species and individuals of species, which that habitat can support. The objective of environmental management is to formulate developmental programmes in such a way as to minimize or avoid suppression of the carrying capacity of the particular habitat in which the programme is to take place.

## 3) THE ENVIRONMENT.

### 3a) POOLE HARBOUR - ITS INCEPTION AND STRUCTURE.

[Fig.1]

Poole Harbour lies in the path of the former Solent River, which flowed across the area 60 million years ago. Consequently, the shores and bed of the Harbour are underlain by fluvial (river) deposits - the bagshot beds - a soft, erodable combination of quartzitic sand with bands of clay. By the last ice age (approx. 10,000 years ago) a smaller river system flowed across what is now the main Harbour, i.e., an extension of the present Frome / Trent system, receiving tributaries such as the present Sherford River, then extending across what is now Lytchett Bay (Fig.1). Poole Harbour was formed after the last ice age by marine submergence of the lowlands surrounding the former river system. This incursion was brought about by a combination of rising sea levels and sinking of the land mass. Freshwater peat, extracted from a depth of 12.8m below chart datum and overlain by marine clays, was radiochemically dated as being 6000 years old, indicating this to be the approximate time of birth of the Harbour (Bird and Ranwell, 1964). Since that time, sedimentation - the accumulation of fine deposits introduced by rivers - has kept pace with the rise in sea level, to form the extensive, deep mudbanks characteristic of much of the Harbour today. Originally,

the Harbour was probably in communication with Poole Bay and the English Channel beyond, across a broad front, but at present, sand bars form a barrier across its mouth, the only communication being through a narrow link-channel only 350m in width. (fig.1). The inception of the Harbour is considered in detail by Bird and Ranwell (1964) and by May (1969).

3b) FUNCTIONAL CLASSIFICATION OF POOLE HARBOUR AS AN ECOLOGICAL SYSTEM.

[Fig.1,2,3]

The term 'natural harbour' is a descriptive, rather than ecological term. The Harbour is a complex of interlinked and largely land-locked basins. The Primary Basin - the main Harbour - was isolated from Poole Bay by the natural migration of sand bars across its mouth (fig.1). In recent times, a succession of subsidiary basins have been artificially isolated from the Primary Basin by the impoundment of former inlets along the northern shore. The largest such basin is Holes Bay itself, which was originally a deep inlet with a fairly narrow entrance, located on the central northern shore of the main Harbour. This has become increasingly isolated from the primary basin by the construction of wharfs, quays and seawalls in the Port of Poole, which has constricted the mouth of Holes Bay to a very narrow Link-Channel (fig.1,3).

The introduction of embankments associated with construction of the Bournemouth - Poole - Wareham railway in the last century, considerably modified the structure of the north part of Poole Harbour. In the early 1800's, Lytchett Bay was turned into a secondary basin by construction of an embankment across its mouth with a single small link-channel. In the 1880's, Holes Bay was sub-divided into inner / tertiary and outer / secondary basins by introduction of another railway embankment, continuity between the basins only being maintained via two small link-channels (figs.1,2,3). At the same time, an isolated secondary basin was created by impoundment of a small inlet to the east of Poole Town to form what is now the boating lake in Poole Park (fig.1). A sluice between this and the Primary Basin is usually kept closed. A small, natural basin east of Poole Town - the 'Blue Lagoon' (former 'Little Sea') - has been artificially, further isolated, by construction of breakwaters (fig.1).

All of these basins are 'brackish', i.e., they contain a mixture of fresh and seawater. This is so because although freshwater input via the small rivers is limited compared to the area of the basins, mixing with seawater is also limited by the narrowness of the link-channels (fig.1).

Three inter-grading categories of coastal indentation are generally recognised:

- i) Bay: Semi-enclosed indentation. Open circulation with the adjacent sea. Good flushing.
- ii) Embayment: More enclosed than Bay. Circulation with the adjacent sea via narrow inlets. Substantial freshwater input induces entrainment flow. Tidal flushing poorer than for a Bay.
- iii) Lagoon: Very confined coastal indentation. Restricted inlets so tidal circulation is limited. Little freshwater input so entrainment is slight or absent. Flushing is very poor indeed.

Because of poor flushing, lagoons are generally regarded as high-risk environments from the viewpoint of pollution. Any

pollutants that are introduced are retained rather than dispersed. Lagoons are also the easiest of the three categories of coastal formation to infill.

Structural evidence alone - large land-locked area, relatively small link-channels (inlets), little freshwater input - suggests that the categorization of the basins of Poole Harbour falls between embayment and lagoon. The exception is the park boating lake, which is a definitive lagoon. Of the others, the main Harbour is the least lagoon-like, whereas the secondary are more-so, and the confined tertiary basin in Holes Bay, is the most lagoon-like.

Further evidence, as outlined below, indicates that the basins of Holes Bay in particular, and Poole Harbour in general, exhibit the same overall ecological characteristics of lagoon-type systems in other parts of the world, and are also facing the kinds of substantial pollution and other stress problems which have occurred in some of these systems.

### 3c) HOLES BAY - NATURAL STRUCTURE; PAST, PRESENT AND PROPOSED ARTIFICIAL MODIFICATIONS.

[Figs.1,2,3,4]

As with the majority of the Harbour, Holes Bay is a 'quiet water' basin, floored with bagshot material and freshwater peat, overlain with up to 10m of mud ( in this report, silts and clays, i.e., sediments with a particle size of <63um, are referred to as mud - see section 2g). The pattern of tidal drainage establishes the distribution and nature of the network of intertidal and subtidal channels scoured into the sediment. This pattern is dependant on the distribution and size of freshwater inputs and on the gross shape of the basin. The channel system in Holes Bay has probably always exhibited its present Y configuration, this being induced by the separation of freshwater inputs from the north-east and north-west by Pergins Island, which is an outcrop of bagshot bed (figs.2,3). 'East' and 'West' Channels extend from these points of freshwater discharge to the centre of the basin, where they meet. A united 'South' Channel extends south-east from the point of confluence, before swinging due south and out into the main harbour as the 'Link-Channel'. The original natural shoreline of the basin was as indented as is that of Lytchett Bay to the west, today (fig.1).

Until a century ago, artificial changes were localised to the shores flanking the mouth of Holes Bay, i.e., in the Port of Poole. The Link Channel, which has always been narrower than the mid / upper reaches of the Bay, has become increasingly constricted by the construction and extension of wharfs and seawalls. The accurate Hydrographic Survey Chart, prepared for Holes Bay (and the rest of Poole Harbour and Bay) in 1849 by Capt. Sheringham, has been used to derive fig 2a. This shows the shoreline and the configuration of the intertidal / subtidal channel system of that time.

The first major changes in the mid / upper reaches were brought about in the 1870's when the railway was constructed. This passed north from Poole Town, along the east shore so cutting off several small inlets, before passing west across the Bay, effectively dividing it into the north and south basins. The east and west link -channels in the embankment were built in-line with the natural East and West Channels of that time (fig.2a,b).

A substantial area of the south-west part of the southern basin was infilled during the 1930's, to create a site for the construction of an oil-fired, seawater-cooled power station (now

rarely in operation). The area of infill was entirely intertidal, bound to one side by a wharf following the line of the Link-Channel (fig.4). Wharfage and seawalls have also progressively occupied the intertidal flats on the opposite, east side of the Link Channel, and along this waterfront are located a number of boatyards, a marina, and to the north - a chemical factory (fig.4). In the 1970's, an area was infilled to the north of this factory to create a site for the R.N.L.I. boatyard. A large marina has been constructed in the west of the basin (1970's). This involved infilling an intertidal area, and dredging mudflats beyond as far as the subtidal channel to accommodate pontoon moorings (fig.3). Moorings are also located throughout the subtidal channel system of Holes Bay.

The present large-scale infilling within Holes Bay relates to construction of a road (route 9) which will run along the east flank of the Bay. Plans are being considered for additional infilling to support a bridge (route Y), which will link route 9 with a road just north of the C.E.G.B. site. The infilling is taking place in three phases (fig.2b). The first, to accommodate the north section of route 9, was completed in the late 1970's. For this, a section of the intertidal zone of the tertiary basin was infilled. The second, flanking the east part of the south basin, will accommodate the south part of route 9. Construction of the bund impounding the area to be infilled, commenced in February 1983. The third programme, to accommodate route Y, is at the planning stage. The current proposed infill area for this is shown in fig.2b. This would partially sub-divide the south basin of Holes Bay into two.

Past infilling in the approaches to Holes Bay has taken place in order to expand the port. In the early 1970's, the New Quay was extended into the main Harbour basin to accommodate a continental ferry terminal. It is now planned that this will be expanded by a more substantial westward extension of the area of infilling (fig.1,2b).

The connurbation of Poole now surrounds all the shores of Holes Bay with the exception of the north-west, which are flanked by a country park - the Upton House Estate.

The 1982 shoreline configuration of Holes Bay is summarised in fig.2b. In addition to major areas infilled over the past century, current and planned infill areas are shown, as is the intertidal / subtidal channel configuration for 1982. Comparison with the 1849 chart (fig.2a) shows that although substantial intertidal areas of the basin have already been infilled, the gross structure of the channel system, including the positions of some small tributaries, remains largely unchanged. There has been some realignment of the upper East and West Channels. One minor structural difference is the absence in 1982, of a small rise in the South Channel shown on the 1849 chart. This may have been dredged away. One reason why there have been no gross changes, may be the restriction of infilling to date to intertidal areas, following, rather than impinging upon the subtidal channels. However there have been some bathymetric changes which are considered in section 3e. Unseen changes to sediment characteristics, tidal currents, salinity regimes, and to the biological communities, will remain untestable in the absence of appropriate baseline data from the 1840's.

Infill programmes in Holes Bay (north of Poole Bridge) from 1880 to 1982, but excluding route 9 and route Y developments, have reduced the Bay to 98.2% of its 1880 area (estimated value). Phase 1 of route 9 (completed) brings this to 94.5%, phase 2 (in progress) will bring this to 91.6%, and the current route Y plan

with the supplementary infill area, will further decrease this to 90.4%.

3d) TIDAL REGIME IN HOLES BAY.

[Fig.5]

Poole Harbour is situated within an area of the English Channel experiencing a very small tidal range, the mean spring range being only 2m (approx., K.Birkmar, P.H.C. pers.comm.). The tidal cycle in the area is also unusual in that there is a departure from the normal semi-diurnal rhythm. Because of coastal shelving effects, there is a double high tide, i.e., two highs for every low. This is well represented in all the basins of the Harbour, as shown by the hydrographic survey of Green (1940), and by data collected from a continuously recording tide gauge maintained in the Holes Bay Link Channel (Town Quay) by the Hydrographic Section of P.H.C. The phenomenon is consistently well defined during spring tides, with the first larger high being followed by a second smaller one (fig.5). However, during neap tides, climatic effects - atmospheric pressure and wind - have a substantial effect, such that the cycle is inconsistent and unpredictable (fig.5)(K.Birkmar, P.H.C., pers. comm.).

3e) TIDAL VELOCITIES, BATHYMETRY, AND EXTENT OF THE SUBTIDAL CHANNEL SYSTEM IN HOLES BAY.

[Figs. 3,6,7] [Appendix - Survey method A]

Channel width, depth, and the nature of floor sediments - all important ecological considerations - are determined by the strength of tidal currents characteristic of each part of the system, which in turn is largely dependant on the volume of water passing each part of the Bay during each tidal cycle. The presence of artificial structures which may modify flow, such as entrainment walls, wharfs, or bunds delimiting areas of infill, are also important considerations.

A very detailed bathymetric survey of Holes Bay was conducted in 1981 by the Hydrographic Section of P.H.C.. This was undertaken to provide baseline information for a mathematical model constructed by Falconer (1982) to simulate present tidal streams, velocities, and flushing characteristics for Holes Bay, in order to predict possible effects of phase 2 of the route 9, and of the route Y infilling programmes. The model was necessarily generalistic and did not consider localised habitat conditions, important from the viewpoint of the distribution and nature of marine communities in Holes Bay.

In the absence of major infilling or any dredging in Holes Bay during the intervening period between 1981 and the current ecological survey (Aug / Sept 1982), the bathymetric regime is assumed not to have changed, so the data of the former survey has been utilised as baseline information for the present work.

For the purposes of this survey, the extent of the subtidal channel system has been delineated by the chart datum line, and the channel system has been sub-divided into 14 sampling sections (fig.3)

Holes Bay is generally underlain by fine mud, and where tidal currents are weak, relatively shallow channels are scoured out, with high width / depth ratios. This is the case for most parts of the East, West, and South Channels (fig.3). In the Link-Channel, where the tidal volume is high and currents are strong (enhanced by artificial constriction of the channel between the wharfs - 3 knot velocity at Poole Bridge during spring tides), the channel is scoured deep and is free of mud (fig.3).

Localised deep spots with a low width - depth ratio are also found in parts of the mid and upper reaches where currents are locally enhanced. This is the case where flow is artificially constricted in the link-channels of the railway embankment (fig.3), and the deepest part of the entire system is at the point of confluence of the East and West channels, where a rotational current has scoured a steep sided 'Hole' 8.3m below chart datum in depth, and extending to the underlying strata beneath the marine muds. Velocities measured at a temporary recording station established by the Hydrographic Section of P.H.C. in the channel immediately south of the Hole (figs.6,7) gave a maximum value on flood spring tides of 1 knot.

The Hydrographic Survey conducted by Capt. Sheringham (1849) included the measurement of maximum channel depths through the entire subtidal channel system of Holes Bay. A comparison of 1849 and 1981 values at various points through the system is given in fig.3. The deepest part of the system in 1849 was also the 'Hole', which at 10m, was 1.7m deeper than it is today. The East and West Channels were also generally deeper than they are now. In contrast, the Link Channel was shallower. Progressive silting-up of the upper part of the system may, in part, be attributable to flow and scour restrictions resulting from impoundment by the railway embankment, together with a reduction in intertidal area - the result of infilling programmes. The increase in channel depth in the port area is probably attributable to constriction of the Link Channel by infilling.

### 3f) NATURE OF THE CHANNEL BED - SUBSTRATE CHARACTERISTICS.

[Fig.7] [Appendix - Survey methods II,III]

The nature of the substrates constituting the channel-bed, fundamentally influences the kind of marine species present, i.e., different species occur on / in hard consolidated substrates (bedrock / artificial structures), as opposed to unconsolidated substrates (sediments), and different kinds of species colonize different grades of unconsolidated sediment (e.g., gravel, sand, mud).

Since the underlying strata - the bagshot beds - are not consolidated bedrock, the only true large and stable hard substrates present in Holes Bay are artificial ones. These are widespread in the link channel (S1-5) in the form of flanking seawalls, wharfage, and jetties which extend into the subtidal zone (S1-3 - both sides, S4 - east side in entirety and west side in part, S5 - east side in part as far north as R.N.L.I.). Stable hard substrates become scarce beyond S5, the exceptions being the vicinity of Cobbs Quay Marina in S11, and the railway parapets and bridge supports within the railway embankment link-channels (S10, S14). Smaller, less stable hard substrates - small wrecks, pontoons, buoys, debris - are extensively present in most sections of the channel system.

Unconsolidated sediments are usually characterised according to the degree of coarseness as expressed by the Wentworth Scale:

<u>Descriptive term.</u>	<u>Size range.</u>
Boulder	> 256mm
Cobble	256-264mm
Pebble	4-64mm
Granule (gravel)	2-4mm
Very coarse sand	1-2mm
Coarse sand	0.5-1.0mm
Medium sand	0.25-0.5mm

Fine sand	0.125-0.250mm
Very fine sand	0.062-0.125mm
Silt*	0.004-0.062mm
Clay*	< 0.004mm

\* Silt and clay grouped and referred to as mud in this report.

Sediments samples from the 22 grab sampling stations covering all sampling sections were characterised on the Wentworth Scale by particle size analysis (fig.7. Appendix, method II,III).

Seabed sediment coarseness is generally positively correlated with tidal current velocity, and this is the case for Holes Bay.

Where currents are weak (fig.7), the corresponding sediments are fine. S1, which faces the extensive Primary Basin, and hence is not a zone of constricted tidal flow, is floored by mud (fig.7). This quickly changes moving into the link channel between the quays (S2, S3), where the strong tidal flow has prevented mud from accumulating (except at channel edges) such that the channel-floor is very coarse, consisting of gravel, stones of various sizes eroded from the bagshot beds, exposed bagshot strata, peat, and accumulated shells. The sediments of S2 to the east of Poole Bridge are highly disturbed by the ploughing effect of ships dragging their anchors, the accepted procedure as they are towed stern-first out of port. This is not the case beneath and beyond the lifting-bridge (S3), where the sediments are still coarse but more stable. In S4, the channel widens and currents slacken, and the bed is predominantly of sand (with mud in places). In S5, where the channel veers west, the bed is a rather poorly sorted, muddy / sandy / gravel. Beyond this point, currents are generally weak and the channels are floored by fine but mainly stable mud. In S9 of the East Channel - the part closest to the route 9 / phase 2 infill area - the mud is no finer than elsewhere (according to particle size analysis), yet was found to be very fluid and unstable (see below).

The only sections of the mid / upper channels where coarse sediments are found, are in the localised areas of increased tidal flow (fig.7). In S7 (the 'Hole'), the tidal current has cut through the entire 8m (approx.) column of marine mud to expose underlying strata - bagshot material and peat. The sides of the Hole are of firm mud with a high content of intact saltmarsh debris (Spartina). Where tidal flow is constricted beneath the railway bridges (S10, S14), the smaller indentations are floored with coarse gravel, which, in the absence of other suitable materials, is dominated by an accumulation of mollusc shells (Hydrobia sp.) swept from adjacent mudflats. This sediment also contains angular stones of railway ballast origin. A substantial accumulation of cobbles and boulders is present in the dip beneath the West Bridge (S14).

Variations in sediment characteristics through the subtidal channel system are not applicable to adjacent intertidal areas, where currents are generally weaker and scour is less.

### 3g) DREDGING DISTURBANCES.

One advantage for the port of the area between the quays (S2, S3), is that the strong tidal currents and scour render dredging unnecessary. None takes place in channels north of Poole Bridge, since, with the exception of S3, only shallow draught vessels use these channels. Dredging does take place in the immediate vicinity of Cobbs Quay Marina (S11) (K. Birkmar, P.H.C., pers.comm.).

3h) SALINITY REGIMES:

[Fig.8] [Appendix - Survey method IV]

Salinity, is an indicator of the degree of mixing of fresh and marine water within a brackish-water system. Salinity regime is a primary factor determining the distribution of species within such systems. Most species living in brackish waters are of marine rather than freshwater origin, and the degree of penetration into brackish zones will depend on their ability of withstand reduced salinities. Some species have become specialised to brackish conditions alone. Salinity regime of a particular habitat - a location within a brackish system - is the maximum range of salinities present over each tidal cycle. This will vary between neap and spring tides and usually also according to season.

The English Channel adjacent to Poole Harbour exhibits a full salinity of 35‰ (35 parts per thousand, freshwater being 0‰). Although Poole Harbour is large in area and the rivers are small (fig.1), the lagoon-like structure means that mixing between basins and the open sea is also limited, such that salinities within the system are generally lowered. Salinity gradient changes across the basins are generally gradual, only becoming steep in the vicinity of freshwater inputs. In the basins of Holes Bay, the only substantial and consistent freshwater inputs are from the streams and sewage effluent outfall, which discharge into the east part of the north basin (fig.7). The municipal storm drain outfall covering Poole Town, intermittantly discharges into the Link-Channel (S2, Town Quay).

Salinity readings were taken at stations throughout the channel system, at low and high water, on days of peak neap and spring tides in August 1982 (fig.8).

Salinities in the part of the Primary Basin adjacent to the Holes Bay Link-Channel were found to be within the range 25-28‰ over the spring tidal cycle. Results for the Holes Bay subtidal channel system, confirm the expectation that levels through most of the system approach those of the adjacent Primary Basin. There is a gradual decline in salinity moving up through the system, but the salinity at any one point is stable, changing little over the tidal cycle (fig.8). From the biological viewpoint, the salinity regime of most of the system can be classified according to the Venice Convention (1958) as polyhaline (in the range 30-18‰). The exception is the East Channel, which receives freshwater input from the streams and sewage outfall. Moving upstream, salinity declines and the range over the tidal cycle becomes more extreme, such that the upper East Channel falls into a different biological brackish-water regime - the mesohaline zone (i.e., in the range 18-5‰) (fig.8).

3i) WATER TEMPERATURES.

Of all marine environments, shallow and land-locked basins are most influenced by short-term changes in atmospheric temperatures. This is the case for the basins of Poole Harbour, particularly for the secondary and tertiary ones, such as those within Holes Bay (fig.1). Summer highs and winter lows are more extreme than in adjacent open waters, as exemplified by comparing temperatures for Poole Town Quay (P.H.C. data) and Bournemouth Pier (Bournemouth Corporation Data). During the hot August of 1976, the maximum temperature at Poole was 24.4°C, 2°C higher than at Bournemouth, and during the severe winter of 1977 they fell to 2.4°C and 3.3°C respectively. The biological consequences are that high summer temperatures permit warmer water species to grow and breed (see

below), whereas low winter minima can cause mass mortality, as took place in Poole Harbour in 1963 (Hawthorne, 1963, Crisp, 1964).

### 3j) POLLUTION.

Because of poor circulation and flushing characteristics, lagoon-like basins are very susceptible to being polluted. They are generally regarded as being very unsuitable for the disposal of wastes, since, instead of being dispersed, the latter are retained and incorporated into organisms and sediments.

Each of the three tiers of land-locked basins present within Poole Harbour (primary - secondary - tertiary) is more lagoon-like and more at risk than the one before (fig.1). The exceptionally poor flushing characteristics of Holes Bay, with its secondary and tertiary basins, have been highlighted by the mathematical model of Faulkner (1982), who determined that flushing was particularly poor during the prolonged tidal stands (periods of little flow) characteristic of neap tides. Tidal regime apart, the artificial process of 'lagoonization', i.e., division of the system into basins with narrow restricted interlinking channels, has considerably exacerbated the poor flushing characteristics of Holes Bay, i.e., construction of the railway embankment with its narrow link-channels has effectively subdivided Holes Bay into secondary and tertiary basins, and the constriction of the Link Channel between Holes Bay and the Primary Basin of the Harbour has contributed to the isolation of the former from the latter.

In the late 1960's, Fleetsbridge Sewage Treatment Works, which serves Poole, was opened. This discharges effluent into the east part of the tertiary basin of Holes Bay (fig.3). Significant input of untreated sewage takes place from the numerous yachts and other pleasure craft which moor in Holes Bay. There is no restriction on the discharge of sewage from these. The water in S3-4 is often visibly discolored by effluents. Effluent from the municipal storm drain system for Poole is intermittently discharged via an outfall on the Town Quay (S2).

A number of studies have shown that Holes Bay is polluted in several respects (see below), and monitoring is carried out by the Wessex Water Authority; Ministry of Agriculture Fisheries and Food; and by the Marine Biological Association of the United Kingdom on behalf of the Department of the Environment. Pollution in Holes Bay, or any sub-system within Poole Harbour may have consequences for the Harbour in general, in that since the primary basin is land-locked, pollutants that do pass beyond the particularly polluted section, will be circulated to other parts of the system, before being dispersed.

Pollutants are major suppressors of carrying capacity of the system.

### 3k) EUTROPHICATION AND THE 'SEAWEED PROBLEM'.

When excessive quantities of plant growth promoters - ammonia, nitrates, phosphates - are introduced with agricultural run-off or sewage effluents, into an enclosed system such as the basins of Holes Bay, they act as a fertilisers, boosting the proliferation of benthic macroalgae (seaweeds) and of phytoplankton. This leads to the problem known as eutrophication. The system becomes overloaded. It cannot cope with the excessive quantities of decaying vegetation that are produced. Large quantities of oxygen are required by bacteria to break down this accumulating organic material, and the usual consequence is that oxygen demand exceeds

supply leading to oxygen depletion, rendering the water unfavourable to many species. The organic debris accumulates on the seabed and is incorporated into the sediments, where degradation continues. If the amount of organic material is large and the sediment fine, such that infusion of oxygenated water is limited, all the oxygen in the sediment is used up, the consequence being that the sediment becomes totally anoxic. Bacteria continue the degradation process without oxygen. The sediment becomes blackened and foul-smelling because of chemical changes which include the release of ammonia and hydrogen sulphide, as well as production of other toxins. Such sediments are inhospitable to all but a few resistant species.

Lagoons and other similarly enclosed basins are very susceptible to eutrophication because they are naturally very enriched. They naturally act as traps for organic debris and nutrients, and are warm and well illuminated in summer. For these reasons they are capable of a high carrying capacity, however the introduction of excess nutrients quickly overloads such a system.

Eutrophication, which has been a problem in Holes Bay for a decade or more, has been subject to investigations by several workers including Ho (1975) and Portsmouth Polytechnic (1981). The latter found levels of nutrients in Holes Bay, particularly ammonia, to be exceptionally high in comparison with other systems on the south coast of England, and the intertidal sediments of the east part of the tertiary basin (fig.3) were found to be anoxic and impoverished. First evidence of eutrophication was the proliferation of chlorophytic macroalgae (green seaweeds) - particularly Ulva lactuca (sea lettuce) and Enteromorpha spp. - in various parts of the basins. Sterte Bay on the east flank of Holes Bay has received particular attention. Two investigators - Arnold (1971) and Haynes (1981) have commented on the anoxic nature of surface mud and the prolific stands of Ulva lactuca growing on the intertidal flats. This was still found to be the case during the current survey in August 1982. However, Sterte Bay falls within the area to be infilled for phase 2 of the route 9 programme, and this was in progress in February 1983.

During the 1970's, problems were encountered with the running of Poole Power Station, which drew water from Holes Bay (S3 - fig.4) and discharged heated effluent into the Primary Basin. Filtration screens were becoming clogged with detached, drifting Ulva drawn in with the cooling water. In solution, a maceration plant was incorporated into the intake, which reduced the Ulva fronds to manageable fragments. Unfortunately, Ulva - as with many seaweeds - continues to survive and grow whilst drifting, and if shredded, the fragments will regenerate into new plants. The problem has subsided for the present in that the power station is now rarely in operation.

Eutrophication and its consequences are very important ecological considerations in that they detrimentally alter the distribution and abundance of biota, and substantially suppress overall carrying capacity of the affected system.

31) ORGANIC CONTENT AND ANOXIA IN SUBTIDAL SEDIMENTS OF HOLES BAY.  
[Fig.9] [Appendix - Survey methods II,V]

As described above, levels of organic content in sheltered, enriched sediments of lagoon systems are naturally quite high (Barnes, 1980), but will be further boosted by eutrophication. Organic content is also important from the viewpoint of toxic metal pollution, since many metals, as well as other toxicants, are incorporated into sediments by association with organic

material (see below).

Organic content was estimated for sediment samples collected at the 22 grab stations by the incineration procedure (see appendix - values expressed as percentage weight of organic carbon). Levels vary considerably through the system (fig.9). As would be expected, levels are lowest in the coarse, current-washed sediments of the outer Link-Channel (S2,S3 -1-2%) and these sediments are not anoxic. Levels were higher in the sands of S4 (4%) and higher still (5-10%) in the fine muds of S1, S6, S8, S12, S13. This broad negative correlation between organic content and sediment particle size is typical, since organic debris settles-out in quieter waters, and is more readily 'locked' into the finer sediments associated with such areas.

The muds from the sides of the 'Hole' (S7) were found to contain a very high proportion of organic material. This was anticipated, since visual examination of the sediment from here revealed a high content of fibrous saltmarsh plant material - especially Spartina debris, incorporated into the sediment after becoming trapped in the Hole. High levels of organic material were also found in S9 and S10. The 14% organic content of this mud may account for its instability and fluidity. Portsmouth Polytechnic (1981) suggested that high organic content was precipitating the degradation of intertidal mudbanks in the tertiary basin immediately north of S14. The gravel within S14 was found to contain 15% organic material, which is unusual for a coarse sediment. High organic content was also found to be the case for mud in S11 (fig.9).

With the exception of S2 and S3, sediments - coarse and fine - of all sections were found to be black and anoxic, even at the surface.

### 3m) TRACE METAL POLLUTION.

Many agricultural, domestic, and industrial chemicals contain what are known as trace metals. These are important pollutants in that they are not degraded with time, and can persist within a system for 100's of years. In the short term, they can be taken-up by marine organisms, and within the longer term they can become incorporated and 'locked' within the sediments. One important characteristic of many mollusc shellfish such as oysters, is that they accumulate certain trace metals in concentrations far higher than in the surrounding water.

Some trace metals are highly toxic to marine organisms. The following ranking of the degree of toxicity, based on compilation of data from tests with many marine and other organisms is by Waldichuk (1974):

MOST TOXIC: Mercury > Silver > Zinc > Nickel > Lead > Cadmium > Arsenic > Chromium > Tin > Iron > Manganese > Aluminium > Beryllium > Lithium : LEAST TOXIC.

There is evidence from several sources that elevated levels of certain toxic trace metals are present within marine organisms and sediments in Holes Bay.

Elevated levels of cadmium within Ulva (sea lettuce) and Ostrea edulis (native oyster) were first reported for the basins of Holes Bay by Boyden (1975). A survey by M.A.F.F. confirmed the presence of this metal in oysters. In September 1976, the S.S.D.F.C. designated Holes Bay a Reserve for Scientific Purposes, so prohibiting the capture of all shellfish (bivalve molluscs - cockles, mussels, oysters, e.c.t.) in Holes Bay, i.e., north of

Poole Bridge (fig.3, S3-14). This order has recently been renewed (Mjr. Parker, S.S.D.F.C. - pers.comm.).

More recently, a survey which covered more than 35 populated coastal systems within southern Britain, found that levels of mercury - the most toxic of all trace metals - are also elevated in sediments of Holes Bay, the only other area of England and Wales with higher levels being Liverpool Bay (Langstone, 1982). Total mercury content in Holes Bay surface sediments was found to be 3.49 ug/g, and it is significant, in view of the high organic content of Holes Bay sediments (see section 31), that Langstone (1982) found a strong positive correlation between organic content and the affinity of sediments to incorporate mercury from the water mass. Hence, enclosed lagoon-like habitats are not only at risk because of poor flushing, but also because of naturally high levels of organic material in sediments, which may, in turn, be exacerbated by eutrophication.

The presence of toxic trace metals is a major ecological consideration, because numerous studies have shown that mercury in particular, and also cadmium, deleteriously affect virtually all the organisms which have been tested. e.g., mercury in low concentrations is toxic to larvae of many marine invertebrates. The presence of toxic metals in an environment does not necessarily cause the absolute failure of populations of marine organisms, i.e., gross distributions and abundances may not change dramatically. Many shellfish tolerate high accumulations of toxins. However, there are many sub-lethal physiological effects, such as interference with fertility, which together suppress population levels of affected species, and hence reduce the carrying capacity of the affected habitat.

#### 4) BIOLOGICAL COMMUNITIES IN HOLES BAY.

##### 4a) METHODS OF ASSESSMENT.

The biological communities occupying the subtidal channels of Holes Bay were investigated by means of an integrated sampling programme of dredging, grabbing and diving. The equipment and procedures are described in the appendix [survey methods II, VI, VII, VIII]

##### 4b) GENERAL TRENDS IN SPECIES RICHNESS.

[Fig.10] [Appendix - Survey Methods II, VI, VII, VIII]

Species richness - the number of species constituting the community occupying a particular habitat, is one expression of its carrying capacity. In general, species richness in the subtidal zone is greater than in the intertidal, since fewer species are able to tolerate the harsher conditions of the latter, e.g., periodic exposure to air (desiccation risk) and extremes of temperature.

A total of 104 species of algae (seaweeds), invertebrates (worms, shellfish and others), and fish were recorded within the subtidal channels of Holes Bay and approaches during the current investigation. However, species richness is not homogenous through the system. To show this, the system has been sub-divided into five discrete biological zones, the characteristics of which are outlined below (fig.10):

A] The Outer Link-Channel (S1-3) - Mostly strong tidal flow and scour. The channel is deep and floored by sediments which are

coarse, well oxygenated, and low in organic content. There are extensive stable and unstable hard substrates, and being closest to the Primary Basin, flushing is better than upstream within Holes Bay.

B] The Inner Link-Channel (S4,5) - Weaker tidal flow and less scour than above. The channel is wider and shallower. Sediments are finer, contain more organic material, and are anoxic. Stable and unstable hard substrates are still extensive.

C] The South Channel (S6,7) - In S6, currents and scour are weak. The channel is narrower and shallower than in [B]. Sediments are much finer, exhibit a higher organic content and are anoxic. In S7, currents and scour are locally strong. The channel is narrow but very deep. Sediments of the channel sides are fine, exhibit a very high organic content, and are anoxic. Channel centre sediments are very locally coarse. Stable or unstable hard substrates are rare in S6-7.

D] The West Channel (S11-14) - Currents and scour in S11-13 are weak. The channel is very narrow and very shallow. Sediments are fine but stable, exhibit a high organic content and are anoxic. Stable and unstable hard substrates are rare.

In S14, currents and scour are locally greater. The channel is narrow but deeper than in S11-13. The sediment is coarse but exhibits a high organic content and is anoxic. Stable hard substrates in the form of artificial structures and artificially introduced boulders are locally common. Flushing is very poor.

The salinity regime of the above zones, A,B,C and D, is polyhaline and fairly stable.

E] East Channel (S8-10) - currents and scour in S8-9 are weak. The channel is very narrow and very shallow. Sediments are fine. In S8, they are also firm and stable, exhibit high organic content and are anoxic. In S9, they are fluid and unstable, exhibit a very high organic content, and are anoxic. Stable or unstable hard substrates in S8-9 are rare. In S10, currents and scour are locally strong. The channel is narrow but deeper than in S8-9. The sediment is coarse, but exhibits a very high organic content and is anoxic. Stable hard substrates in the form of artificial structures are locally extensive. Flushing in S8-S10 is very poor.

The salinity regime in S8 is polyhaline, but less stable than in [A],[B],[C] or [D]. The salinity regime in S9-10 is mesohaline and more unstable still.

Species inhabiting the five zones can be divided into three broad categories:

i] Highly motile species, which have the capability to freely move between zones (fast-moving crustaceans, fish).

ii] Species associated with unstable or stable hard substrates (epibenthos and infauna - borers).

iii] Species associated with unconsolidated substrates (epibenthos and infauna).

The variation in numbers of category [ii] and [iii] species between the five zones is shown in fig.10. There is a general decline in numbers of species of both categories, moving from [A], the richest (total of 69), through [B,C,D,] (56, 36, 33), to [E],

the poorest (25).

The two species categories - hard and unconsolidated - generally decline in proportion, the ratio being approximately 2:1 in all zones except [D], for which the ratio is 1:1.

The general trend can in part be accounted for by changing substrate characteristics. In [A], hard substrates are extensive and unconsolidated sediments are coarse and well oxygenated. Both these features decline moving towards the upper reaches such that in [D] and [E], hard substrates are scarce and the sediments are fine and anoxic. The substantially lower number of unconsolidated species in [E] as compared with [D] may be related to the differing salinity regimes - three hard-substrate species unique to [E] are thought to be brackish endemics. Water quality may also be implicated. Boyden (1975) recorded elevated levels of trace metals in the upper part of this channel [E], and high levels of organic content were recorded there during the current survey.

The species richness results provided above and in fig.10 are provisional, and are used only to illustrate overall trends. A definitive species list, including distributions and abundances, will be lodged with the N.C.C. in due course.

4c) BIOLOGICAL COMMUNITIES ACCORDING TO SUBSTRATE TYPE.  
[Figs.10,11] [Appendix - Survey Methods II,III,VI,VII,VIII]

i) Species colonizing muds.

Soft anoxic mud is the most extensive substrate type within the subtidal channels of Holes Bay (fig.7). Although richest in organic content - a potential food source for infaunal species - the muds were found to contain the poorest communities of the system, both in terms of species richness and abundance of individuals of each species. Anoxia - the absence of oxygen - and the presence of toxins associated with this (see 31), renders the muds unsuitable for inhabitation by many burrowing (infaunal) species,. Highly tolerant species and those which maintain a link with the surface are the exceptions. The softness of the channel floor means that it is unable to support larger epibenthic species.

Species of Cerastoderma (cockles) are the dominant feature of the subtidal muds in Holes Bay, both in terms of numbers of live individuals, and of accumulated dead shells. Dead shells were commonly found in the muds of all sections of the system. However little concerning current population levels can be deduced from this, since shells can remain intact in such substrates for hundreds of years. The mean accumulation rate of mud in the centre of Holes Bay over the past 6000 years has been approximately 1.3mm per year. This rate has probably increased substantially over the past century as the result of impoundment and infilling influences. According to this mean rate, the top 20cm of sediment may contain shells which accumulated on the channel bed up to 150 years ago. Densities of living cockles in the subtidal mud, as established by grab sampling, were generally low (fig.11). The highest densities were found in the sandy areas of S4-5 (see below).

Two cockle species inhabit sheltered lagoon-like ecosystems - Cerastoderma edule (typical edible cockle) and C. glaucum (lagoon cockle). These are not easy to differentiate, since they often occur in mixed populations and it is thought that they hybridize. C.glaucum has been previously recorded in the boating lake of Poole Park, which is a true lagoon (Boyden & Russell, 1972). It generally does better than C.edule in areas where fine muds coincide with extreme shelter and low salinity, as is the case for

the mesohaline East Channel of Holes Bay. Dead shell specimens from this area display intermediate characteristics between the two species, and detailed morphometric analysis is being conducted to establish which of the two occurs where, within the channel system.

Other bivalve species were only represented by dead shells in the muds, e.g., shells of the intertidal mud species Scrobicularia plana, frequently found in the subtidal muds, were probably swept from adjacent mudflats. One feature which may be important is the localisation of two bivalve species to the upper and mid sections of the west channel. Macoma balthica is an estuarine species typical of muddy substrates, and Mya arenaria (gaper) is an open coast and estuarine species commonly found in intertidal and subtidal muds. Large numbers of dead shells of these two species were found in S12 to S14, but nowhere else. There is no obvious natural reason why these species should not be found in other parts of the basin with similar sediment structures and salinity regimes, so localisation because of poorer water quality elsewhere in the basin should be considered as a possibility.

Very few burrowing annelid worms were found to be present within the muds. Nereis spp. (ragworms) and Nephtys caeca were sporadically encountered. Populations of Nereis diversicolor (common ragworm) from other polluted brackish-water localities are known to have developed resistance to the toxic effects of some trace metals.

The poorest muds of all were those in S9, adjacent to the area to be infilled for the second phase of route 9. Here, the unstable, fluid, and organic muds were azoic - supporting no living infauna at all. It is likely that the physical instability of the sediment - which may flow during spring floods and ebbs - contributes to the prevention of colonization. Cockles and other shellfish would not be able to maintain themselves on the soft surface, and burrowing worms could be displaced to depths well below the surface of the flowing mud. As suggested in section 4b, low salinity, anoxia and trace metal pollution may also have a bearing on the poor biotic content of this part of the system.

#### ii) Species colonizing sands.

Sand is the dominant feature of sediments of the Inner Link-Channel (S4-5) (fig.7). Although the sediment here is anoxic, organic levels are lower than in the mud and circulation is better. The firm and stable sand, littered with dead shells maintained silt free by moderate tidal scour, provides a good substrate for the support of larger epibenthic, filter-feeding molluscs. These are maintained free of silt by the scour, and receive a good supply of particulate food carried by the current. This sandy area contains the richest epibenthos of unconsolidated substrates within the channel system. The channel-bed is covered by a mixture of filter-feeding molluscs - Crepidula fornicata (slipper limpet), Ostrea edulis (native oyster), and in S5 only, Mytilus edulis (edible mussel). Past investigations have shown shellfish in this area to be contaminated with cadmium (Boyden, 1975). Styela clava (Korean sea squirt), another epibenthic species, is locally common in S5. The largest numbers of live cockles - probably all Cerastoderme edule - were encountered in S4-5 (fig.11). Infaunal species such as burrowing polychaete worms, were more abundant in numbers of species, and numbers of individuals, than in the muddy areas.

#### iii) Species colonizing coarse gravelly sediments.

The disturbed and coarse, unconsolidated sediments of S2, were

found to be poorly colonized by infauna. Although well oxygenated, the weight and angularity of constituent particles, in conjunction with frequent artificial disturbances, renders this substrate inhospitable for delicate burrowing species such as polychaetes, and impenetrable for burrowing bivalve molluscs. Very few of the former were encountered here, and none of the latter.

In contrast, the less disturbed, stable and coarse sediments beneath the lifting bridge (S2/S3), which are also current swept and oxygenated, are colonized by a rich infaunal community of polychaete annelids - the richest of the system - dominated by deposit feeding species: Cirriformia tentaculata and Amphitrite johnstoni, were present in densities of 230 and 40 per sq metre respectively (grab sample data - see appendix).

No infauna at all was encountered in the coarse, gravelly sediments of S10 and S14. These combine impenetrability with anoxia. The unconsolidated substrate epibenthos was also poor - one individual Ostrea edulis (native oyster) in S14.

iv) Species colonizing peat or clay.

Freshwater peat and clay are exposed by tidal scour in S2-3 and S7. Detached 'clay spheres' are common in muds throughout the channel system. Dead shells of Petricola pholadiformis (american piddock), an introduced species which burrows into peat and clay, were sporadically present in sediments throughout the system.

v) Species colonizing small unstable hard substrates.

Numerous smaller sessile invertebrates such as cnidarians, annelids, and bryozoans, occur on small hard-substrates such as stones, shells, and small debris, liable to roll in the current. A prerequisite is that the surfaces should be scoured fairly or completely free of silt. Such substrates are most prevalent in S2 and S3, where the current-scoured channel floor is littered with a mixture of stones and shells (especially Ostrea edulis). In S4 and S5, where currents are weaker and silting is greater, stones are uncommon. However, accumulated 'dead' shells of the molluscs which proliferate in this area provide abundant silt-free surfaces for colonization. Shells of Crepidula fornicata (slipper limpet) and Cerastoderma spp. (cockles) are dominant.

In sections floored by muds, the characteristically high Cerastoderma shell content is unavailable for colonization, because in the absence of strong scour, shells are buried by sedimentation.

v) Species colonizing large, stable hard-substrates.

This community is particularly well developed in S1-3, i.e., on the sheltered and current swept, subtidal surfaces of wharfs and seawalls. It consists almost entirely of filter-feeding sessile invertebrates, and in terms of substratum occupancy (% area of substratum occupied), it is dominated by sponges (7 species). The large orange mound sponge - Suberites massa (species identified by S.Stone, British Museum of Nat. Hist.) - by far dominates this community to the extent that in places it forms a virtual monospecific, 100% cover. This sponge also dominates the lower shore in places. Another sponge - Haliclona oculata - is also very common. Filter-feeders from other invertebrate groups which are well represented, include two ascidians (sea squirts) - Ascidiella aspersa and the introduced species Styela clava, and to a lesser extent, various hydroids and bryozoans. This high occupancy and high biomass community has developed in response to a combination of factors: Shelter from wave action allows development of large

delicate forms such as S.massa and H.oculata. Strong tidal flow maintains the organisms free of silt and provides a good supply of suspended particulate food such as organic detritus and bacteria (the latter are usually very abundant in systems receiving sewage effluent, and it is known that many sponges grow very well on bacteria from sewage). Suberites massa occurs throughout the system in Holes Bay, wherever current-swept and stable hard-substrates are to be found.

vi) Motile species not associated with particular substrates.

This important group is dominated by crustacea (crabs) and by fish, all of which are fast-moving, are able to traverse substantial areas of seabed irrespective of the nature of underlying sediments, and feed on many of the species described above.

CRABS: Carcinus maenas (shore crab) - a typical estuarine species - is very common in all parts of the Holes Bay channel system. It is a scavenging predator, able to feed on dead and living prey. It often predated juvenile oysters (Ostrea edulis) and mussels (Mytilus edulis). C.maenas was found, associated with all substrate types. Juveniles frequently occur in association with the sponges community on the jetty walls. Large numbers of juveniles and adults occur in the muddy areas of the channels. The highest concentrations were found in the upper East Channel (S10). At high tide, most of the crabs move over the intertidal mudflats in search of food. The subtidal channels are their refuge at low tide. The large numbers of crabs confined to the subtidal channels at this time, may exert heavy grazing pressure which may, in part, account for the paucity of the epibenthos of the mud in these areas.

FISH: A number of fish species were found to be common in the subtidal channels of Holes Bay:

Juvenile flatfish, particularly Platichthys flesus (flounder) and Pleuronectes platessa (plaice) (or plaice / flounder hybrids) were caught in quantity when dredging the channels at low tide - particularly in the Hole (S7). Small numbers of juvenile Solea solea (Dover Sole) were also captured. This confirms the expectation that the basins of Holes Bay, as is the case for many sheltered and enriched brackish ecosystems, is a nursery feeding ground for juvenile fish which subsequently leave the Harbour to be recruited to inshore adult stocks which may be commercially fished. As with the crabs, the juveniles graze intertidal mudflats at high tide and retreat to the refuge of the subtidal channels when the tide is out.

Adult fish of other species common in Holes Bay, include Mugil labrosus (thick-lipped mullet). This also grazes the intertidal flats when the tide is in, retreating to the subtidal channels at low water. This species, which is frequently found in brackish lagoons, feeds on intertidal mats of algae (seaweeds) on the sediment surface as well as on organic detritus (Barnes, 1980). It is perhaps significant that the largest numbers of grey mullet are found in the upper reaches of the East Channel (S9,10), which may be the most eutrophicated part of the system.

Adult Anguilla anguilla ('freshwater' eel) are also common in Holes Bay, as they are throughout Poole Harbour.

4d) COMMERICAL FOOD SPECIES.

[Figs.11a,b] [Appendix - Survey Methods II,VI,VII,VIII]

i) OYSTERS.

The main basin of Poole Harbour, with its firm sediments,

moderate tidal flow, and rich particulate food supply, is capable of supporting very large populations of oysters and other commercial, filter-feeding bivalves. Originally, the Harbour contained a very substantial intertidal and subtidal population of Ostrea edulis (native oyster), and this was probably first exploited as a fishery by the Romans. The area of the Port of Poole has long been the centre of a large oyster fishery, and much of the old town is built on accumulations of oysters several metres in thickness. The commercial fishery continues, but at declining levels, and various parts of the bed of the Main Basin are farmed by companies and part-time individuals alike. The shellfishery has been expanded in recent years to include introduced species such as Crassostrea gigas (Pacific Oyster) and Mercenaria mercenaria (American Clam, or 'Quahog'). The latter was introduced in the 1960's (Ansell *et. al.*, 1964), but did not take well in the harbour, although small numbers are still to be found in the area of the Hamworthy foreshore (Collins, 1979). Cockles are fished for in the Harbour on a small scale. The commercial oyster populations on beds south of the area to be infilled for extension of the ferry terminal (fig.1,3) are being monitored (Collins, 1979; 1980; in progress).

Because Holes Bay has been designated a Reserve for Scientific Purposes, it is an unexploited and undisturbed shellfishery (see section 3m). The current survey shows that beds of Ostrea edulis are localised to the Inner and Outer Link-Channels (S1-5) and that numbers are greatest in S5. This is the area where Boyden (1975) found oysters with the highest cadmium concentration - 53.7ug/g (also see section 3m). It seems likely that oysters have been localised to this part of Holes Bay for a very long time, since not even oyster shells were found in the sediments further north. This limitation is related to substratum availability and not salinity regime. Oyster larvae settle out and attach to small unstable hard substrates such as shells (culch) or stones. Since most of the channel floor north of S5 is of soft fine mud, it is unsuitable for settlement of oyster spat. A single large individual was found on the gravel of S14. The other unexploited food species common in Holes Bay, are the cockles. No Crassostrea gigas or Mercenaria mercenaria were found (live or shell) during the current survey. Even though the shellfish of Holes Bay cannot be fished, they do constitute breeding populations which produce spat that can be recruited to the beds of the primary basin.

ii) FISH. Several small commercial fisherman and numerous recreational anglers catch fish in Holes Bay. Perhaps the species most consistently fished for is Mugil labrosus, which is gill-netted in the upper East Channel. Small fishing boats occasionally trawl the narrow channels for flatfish, catching flounders in particular.

Although Holes Bay does not constitute an important commercial white-fishery, as outlined above, it is important as a nursery ground for juveniles of commercial fish species, which are subsequently recruited to open coast adult grounds.

#### 4e) PEST SPECIES.

[Fig.11a] [Appendix - Survey Methods II,VI,VII,VIII]

Several species which are pests of oyster beds or nuisances in other respects, are present in Holes Bay.

The most significant of these is Crepidula fornicata (slipper limpet), an introduced species which lives in the same habitat as Ostrea edulis. It proliferates on oyster beds and smothers the

original inhabitants. Many oyster beds in British estuaries are swamped by vast accumulations of slipper limpets. The limpets do not feed on the oysters. Crepidula is found throughout Poole harbour, and has infested the oyster beds in the link channel of Holes Bay. The distributional cut-off point for this species is S5, the same as O.edulis, and for the same reasons.

A single dead shell of Urosalpinx cinerea (American Oyster Drill) was found in S2 during the present survey (fig.11). This species is a vigorous predator of oysters. It bores a hole through the oyster shell and feeds on the soft living tissues within. It is a very serious pest of oyster beds on the east coast of England, but until now, there have been no records of its occurrence on the south coast, i.e., within the Southern Sea Fisheries District. The native equivalent - Ocenebra erinacea - is a problem in the Solent area, but even this does not occur in quantity in Poole Harbour (Maj. Parker, S.S.F.C., pers. comm.). In the absence of other records, Urosalpinx does not as yet, appear to be established in Poole Harbour. The current specimen was collected near to plants recently operated by two oyster fishing companies, however it seems unlikely that these are the source, since the movement of oysters (with pests) between districts around England is restricted, to prevent the spread of such pests and diseases (D. Key, M.A.A.F., 1977, pers. comm.).

Sargassum muticum (Japweed) is another introduced species which became established on the Isle of Wight during the early 1970's (Farnham et.al. 1980). Since that time, it has spread east and west along the southern coast of England. It grows, attached to small stones in sand, to boulders, bedrock, or artificial hard substrates S.muticum is a problem because of the length of the fronds and their density. It proliferates in sheltered embayments and harbours, and as such, is a nuisance for small boats that use the waterways. One characteristic that enhances the spreading capability of this weed is that the fronds contain floats, and detached, drifting fronds continue to grow and reproduce for a considerable period of time. In August 1977, the author surveyed shores in various parts of the Harbour, but the weed was not present at that time. In 1978, substantial quantities were found during the resurveying of a shore in the Haven area. Since that time, the population in the east of the Harbour has continued to expand. During the present survey, isolated drift specimens of S.muticum were discovered entangled around buoys in the centre of Holes Bay (fig.11). No attached specimens were found, and it is anticipated that S.muticum will not take hold this far into Poole Harbour, since it cannot survive in areas of low salinity (Farnham, et. al., 1980).

#### 4f) INTRODUCED SPECIES.

In addition to the shellfish and pest species considered above, a number of other introduced species are found in Holes Bay and Poole Harbour in general, and several of these dominate the ecology of the Harbour.

Most introduced species are believed to have been introduced into British waters with oysters transported from other parts of the world. Species may have been introduced directly into Poole Harbour, or via other oyster areas. Others, such as the barnacle Elminius modestus - common in subtidal channels and dominating intertidal hard surfaces in Holes Bay - probably did not arrive with oysters, but with shipping. Styela clava (Korean Sea Squirt) is another example belonging to this second category. Poole is a high risk area for ship-born introductions because it is a world

yachting centre and is close to world shipping centres such as Southampton, Portsmouth, and Portland.

Mid-summer water temperatures in Poole Harbour are higher than in adjacent open coastal waters, so permitting warmer-water introduced species to breed.

#### 5) DISCUSSION AND CONCLUSIONS.

The physical and biological attributes of Poole Harbour have supported and continue to support development of the various human activities, i.e., the port, shellfishery, the urban and industrial base, tourism, and most recently - the oil industry. These processes, which have changed the Harbour in various ways, are inextricably linked with natural processes in the equation, the outcome of which determines the carrying capacity - the ecological health - of the Harbour. For this reason, individual developmental programmes or processes cannot be considered in isolation from others, since they are all interactive. All natural biological components of the system are also inter-related. The health and condition of the most evident of these - the fisheries, or the visually attractive components of the system such as the shores and birds - are dependant on the health of the remainder of the biological component, e.g., on organisms which serve as food for the shellfish, fish, or birds; and others, which unseen, actively maintain the visual attributes of the shores.

Two interactive artificial processes which are major components of the Poole Harbour equation, and are potentially major suppressors of carrying capacity, are as follows:

a) Impoundment - The isolation of one part of the Harbour from another by construction of a barrier, this often being the precursor for subsequent infilling of part or all the impounded area in order to generate land.

b) Pollution, which in Holes Bay includes eutrophication and trace metal contamination.

Impoundment and infilling have been on-going processes along the north shores of the Harbour for the last century. Before this time, Poole Harbour was a very large, naturally land-locked, brackish-water basin, fringed with more or less deep inlets. Such basins have restricted circulation with the adjacent open sea and are naturally enriched, such that they are capable of supporting very high densities of benthic shellfish. This original basin has now been artificially sub-divided, so that parts of the north Harbour have become more isolated than was previously the case, i.e., the southern part of Holes Bay, Lytchett Bay, Poole Boating Lake, and the Blue Lagoon are artificially confined secondary basins; and the north part of Holes Bay is a tertiary basin (fig.1). These smaller basins are more enclosed than the primary, with which circulation and tidal flushing are restricted by various degrees. The limited tidal range and prolonged stands characteristic of Poole Harbour exacerbate this problem. These basins are in effect, artificial lagoon-like habitats. Lagoons are generally characterised by having very poor circulation with adjoining waters, very poor tidal flushing, and are naturally organically enriched and capable of a high carrying capacity. They are also high-risk environments since they are very vulnerable to being polluted, and so are considered unsuitable for the disposal of wastes. Eutrophication quickly overloads the detritus breakdown process and leads to a substantial suppression of carrying capacity, and the high organic content, further elevated by eutrophication, facilitates the incorporation of toxic trace metals into sediments. Trace metal pollution also suppresses

carrying capacity.

Looking more specifically at Holes Bay, the tide-scoured Link-Channel between this and the main Harbour, was the original Port of Poole. This has become increasingly constricted by progressive infilling on both sides, further isolating Holes Bay from the main Harbour. Construction of the railway embankment subdivided the former into secondary and tertiary basins with limited inter-circulation via the two narrow link channels. Areas of the outer basin have subsequently been infilled for the C.E.G.B., marina, and R.N.L.I. developments. Phase 1 of route 9, entailed infilling of the east part of the inner basin, and phase 2, will entail infilling of the east flank of the outer basin. According to the current plan for route Y, infilling will take place on both sides of the outer basin such that the latter will be partially sub-divided. The route 9 and Y programmes will reduce the area of Holes Bay from 98.2% to 90.4% of its 1849 value.

The effects of individual impoundment or infilling programmes cannot be considered in isolation from those which have taken place in the past, since the effects on the environment are stepwise, perhaps gradual, and cumulative. However, predictions can be made concerning the long-term effects of this continual process. The total impoundment and infilling in Holes Bay and approaches to date, including current developments, will have reduced tidal flushing to a degree, and will have increased retention of pollutants discharged into the system. Falconer (1981) mathematically modelled the circulation and tidal currents in Holes Bay in order to predict possible changes to flushing rates and dispersal of pollutants, specifically associated with phase 2 of the route 9 and with the route Y programmes. Flushing and dispersal rates of the system as of now (including phase 1 of the route 9 programme) were found to be very poor indeed, particularly during neap tides (Falconer, 1981). The model suggested that these characteristics may be further suppressed as the result of the second phase of the route 9 project (now underway) although the degree of change, which may be small, could not be predicted with accuracy.

The pollution consequences of poor dispersal in Holes Bay are that pollutants are being incorporated into organisms and sediments. Elevated levels of cadmium are present in oysters. Recently, exceptionally elevated levels (for England and Wales) of the highly toxic metal, mercury, have been reported as present in superficial sediments of Holes Bay. It is well known that such toxins reduce the carrying capacity of the system by interfering with the physiology of marine organisms. In addition, much of the system is eutrophicated: Sediments throughout the subtidal channels of the mid and upper reaches of the system were found to be totally anoxic, charged with a high organic content, and supporting only an impoverished infauna. If the proposed further infilling programmes for Holes Bay do precipitate a further deterioration of flushing characteristics, and input of pollutants into Holes Bay continues, then still higher levels of trace metals would accumulate in biota and in sediments, the deleterious effects of these in reducing carrying capacity of the system would become more pronounced, and these effects could extend to other parts of the Harbour (beyond any present extension).

At present, the richest biological communities of unconsolidated sediments are found in the outer reaches of Holes Bay, where currents are stronger, flushing and scour are better, and the sediments are coarser, less organic and better oxygenated. If tidal currents and scour are reduced further, it would be expected that the finer, anoxic and biologically impoverished

sediments now typical of the mid and upper reaches of Holes Bay, would extend further south. This would accompany a progressive shallowing of channels. It has long been appreciated that the quantity of 'backwater' in any part of Poole Harbour directly influences the navigable depth of channels downstream (Sydenham, 1839).

One significant effect of impoundment is that biological movements are impeded, i.e., free movement of algal spores, invertebrate and vertebrate larvae, motile crustacea and fish, to and from basins of the system, are inhibited, so interfering with biological recruitment, colonization, and migration. Evidence was obtained during the current investigation that Holes Bay, along with the rest of the Harbour, is a nursery ground for commercial fish species. Any interference in the movements of fish in and out of the system may influence stock-levels within adjacent coastal fisheries. Adult fish are also known to feed in Holes Bay.

To date, none of the infilling programmes in Holes Bay have impinged upon the subtidal channels. In fact the channel system has changed little in gross characteristics over the past 140 years. However, infilling of intertidal areas does 'zero' the carrying capacity of these, and also reduces the carrying capacity of other parts of the system by reducing the availability of intertidal mudflats as a food source for crabs and juvenile / adult fish (high tide) and birds (low tide).

The absolute numbers of marine species inhabiting a unit area of hard stable substrate can be much higher than that of the same area of unconsolidated substrate, and this is the case for the extensive, subtidal, artificial hard surfaces of the wharfs in the Link-Channel area which are colonized by a high biomass and species rich community. However, this is no substitute for the unconsolidated substrate community that it replaces in that the kinds of species colonizing the former are not direct food sources for grazing fish or crustaceans.

It is not possible to be more specific or definitive, in that the present investigation is the first to be undertaken of the subtidal communities of Holes Bay. As such, it is a baseline providing an indication of the ecological health of the biological communities in 1982 - 100 years after the commencement of 'lagoonization' and a decade or more after pollution problems first became apparent. Further monitoring will be necessary to establish the actual effects of the developments currently underway. The above general comments on likely effects are based on reports of the effects of comparable projects in other parts of the world. There have been few such studies for the British Isles.

A Hunter grab was used, supplied with peripheral equipment by the Wessex Water Authority Regional Biology Unit. The grab was operated from 'Rough Ryder' - the 11m workboat of Poole Harbour Commissioners - which has a suitable stern gantry. This grab, which retrieves an 0.1sq.m. area of sediment, was found to perform most effectively in the muddy / sandy areas of the channel system, but less so on the coarser sediments of the outer Link Channel, where additional replicates were required. 22 channel-centre stations were sampled, covering all sections (fig.3), and in most, three replicate samples were taken per station. Access to the shallow upper East and West Channels was obtained during high water spring tides. The full grab sampling programme was completed over two days. A subsample was taken from each for particle size analysis, and the remainder was wet sieved (0.5mm mesh size). The retained material, including the constituent fauna, was preserved in seawater formalin for subsequent analysis. In the laboratory, samples were examined microscopically, and all species were identified and counted.

III) Particle size analysis. Each grab sediment subsample was wet sieved (63um mesh) to separate clay / silt (mud) and coarser fractions, in order to establish the weight ratio of the two. Coarser fractions were then dry sieved using a nested sequence of mesh sizes to determine the particle size frequency distribution by weight. Each sediment was categorised on the Wentworth Scale according to the modal point of its particle size frequency histogram.

IV) Survey of salinity regimes. Salinity readings were taken at 13 stations covering all parts of the subtidal channel system, within 0.5h of low and high water, on days of peak neap and spring tides in August 1982. Readings were taken 0.15m below the surface using a conductivity salinometer operated from a P.H.C. open launch.

V) Analysis of organic content. Each grab sediment subsample was dried, decarbonated by acid, and incinerated at 850 C for 45min, the total organic content being established by weight difference.

VI) Oyster dredge sampling. An oyster dredge is in effect a coarse meshed, heavy duty bag, which is towed across the seabed, retaining all material exceeding the mesh size. It serves a different function to the grab in that it semi-quantitatively samples large infrequent objects littering the seabed, such as oysters. A small oyster dredge (2' gape, 2.5" mesh size), supplied by the Wessex Water Authority, was operated from the stern gantry of 'Rough Ryder' (also see II). Three replicate hauls were made, channel centre, the full length of all sections except S10 and S14 (inaccessible). S7 (the 'Hole') was sampled by making circular hauls, rotating the vessel on its axis. The contents of each haul were fixed in seawater formalin and subjected to laboratory analysis. Oysters were counted, and the subsidiary sessile fauna colonizing other substrates retrieved, were identified.

VII) Cockle dredge sampling. The cockle dredge bridges the gap between grabbing and oyster dredging, in that it samples species too infrequent to be retrieved by grabbing, yet too small to be caught in the oyster dredge, i.e., species such as cockles and slipper limpets. A light dredge with 1" mesh was manufactured specifically for the survey. This was operated by hand from a small open launch provided by Poole Harbour Commissioners. Three

replicate hauls were made the length of every section. Mollusc shellfish in the formalin-fixed samples were identified and counted. Sessile biota of small hard substrates (shell, stones) were identified by microscopical examination.

VIII) Dive sampling. None of the above sampling procedures can be used to investigate communities of organisms colonizing subtidal vertical hard substrates (e.g., seawalls, jetties). The technique usually employed is direct observation, photography and sampling by diving. For this to be achieved, some degree of water clarity is required. Clarity was found to be very poor within the channels of Holes Bay. In a curtailed programme, the communities colonizing the subtidal surfaces of the wharfage lining the west flank of the Link Channel (S1-3) was sampled by diving. The work was conducted with the support of the Biological Diving Team of the Wessex Water Authority. An open launch supplied by Poole Harbour Commissioners was used. Underwater visibility proved to be close to zero. The community at two depths - 1.5m and 3m below chart-datum - was examined and sampled at a succession of 9 stations between the Oil Jetty (S1) and the north end of the C.E.G.B. wharf (S3) (fig.4). At each depth, all sessile biota colonizing an area of substrate approximately 0.75m in diameter, was scraped into a sack, brought to the surface, and bagged in seawater formalin awaiting laboratory examination.

6) RECOMMENDATIONS.

It is recommended that:

i) In order to obtain important information on the actual effects of infilling operations in Poole Harbour, monitoring of the consequences of the current programmes - phase 2 of the route 9 project, and the port expansion - should be conducted, so that the effects of future developments can be predicted with more exactness. For the first time for any part of Poole Harbour, the essential detailed reference points for comparison - the results of the various baseline surveys of Holes Bay - have now been established. These are only of value as the basis for comparison against information obtained from repeat surveys.

ii) In order to obtain a balanced appraisal of the ecology of Poole Harbour, such baseline studies should be extended to cover the other sectors of the Harbour. Preliminary investigations conducted by the author on subtidal habitats in other sectors have revealed communities of a different nature to those found during the current survey in Holes Bay.

iii) The kind of programme which impounds and 'lagoonizes' parts of the Harbour should be avoided, since these do create higher risk habitats, with restricted biological movement and reduced carrying capacity, vulnerable to pollution (susceptible to eutrophication, and with the potential to accumulate trace metals), i.e., barriers with narrow link-channels and certainly those without channels should be avoided. Such artificial lagoons that already exist exemplify these problems.

iv) Route Y should be designed as to minimize impedance of tidal flushing and biological movements, by maximising the extent of the elevated sections.

v) In view of the high attributes of the affected system (Poole Harbour), the irreversibility of the infilling process, and the general scarcity of brackish (estuarine) as opposed to terrestrial habitats, it is recommended that infilling be avoided wherever possible, and that essential infilling programmes should be designed to affect the minimum area of the system and to exert minimum effects on natural processes.

ACKNOWLEDGEMENTS.

I am grateful to the various organizations and individuals who provided assistance in many ways:

Nature Conservancy Council: Miss Eve Dennis, overall project coordinator and Assistant Regional Officer of the Nature Conservancy Council in Dorset, provided invaluable consultation and assistance at all stages of the work.

Poole Harbour Commissioners: I thank Cmdr. H. Mules (Chief Executive) for valuable consultation, Capt. W. Allinson (Harbourmaster) and Lieut. G. Wareham (Asst. Harbourmaster) for generous provision of boats and other facilities for the survey work, Mr K. Birkmar (Chief Hydrographer) for frequent consultation and the provision of much of the hydrographic data used in this report, Mr C. Fowler (Marine Foreman) and the crew of 'Rough Ryder' for their skillful assistance with boat operations. The facilities provided by P.H.C. included the use of a quayside office and of a small open launch with fuel for several weeks, and use of the llm workboat 'Rough Ryder' with 2/3 crew (4days).

Poole Borough Council: I am grateful to P.B.C. for generously providing use of the East Quay Lodge over a period of several weeks, as the base for the survey, including specimen processing operations, laboratory investigations, and accommodation. I thank Mr I.K. Andrews (Town Clerk) and Mr R. Parish (Town Clerks Department) for permitting and arranging this provision. I am grateful to Miss D. Stevens (Upton Country Park Warden) for her assistance.

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Southern Sea District Fisheries Committee: I am grateful to Maj. A. Parker, Chief Fisheries Officer, for valuable consultation and provision of a permit, allowing dredging for scientific purposes in the Holes Bay closed fishery.

I am also particularly grateful to Dr. E.M. Burrows, for her advice on the planning of this survey. Miss S. Stone (British Museum) kindly identified the species of Suberites.

The final stages of the work took place in the Department of Zoology of University College Swansea, with the permission of the Head of Department, Prof. J.S. Ryland.

The survey was funded directly by Dorset County Council and Poole Borough Council.

8) APPENDIX - SURVEY METHODS.

I) Delimitation of the extent of the survey area. The subtidal zone of Holes Bay includes all natural and artificial surfaces below chart datum, upstream of the New Quay Oil Jetty (figs.3,4). The chart datum line has been derived from the results of a detailed bathymetric survey of Holes Bay and approaches, conducted in 1981 by the Hydrographic Section of P.H.C..

II) Grab sampling. This technique was employed to obtain samples of the channel bed for particle size analysis, estimation of organic content, and to provide an indication of the range and abundance of species living within the sediment.

A Hunter grab was used; supplied with peripheral equipment by the Wessex Water Authority Regional Biology Unit. The grab was operated from 'Rough Ryder' - the 11m workboat of Poole Harbour Commissioners - which has a suitable stern gantry. This grab, which retrieves an 0.1sq.m. area of sediment, was found to perform most effectively in the muddy / sandy areas of the channel system, but less so on the coarser sediments of the outer Link Channel, where additional replicates were required. 22 channel-centre stations were sampled, covering all sections (fig.3), and in most, three replicate samples were taken per station. Access to the shallow upper East and West Channels was obtained during high water spring tides. The full grab sampling programme was completed over two days. A subsample was taken from each for particle size analysis, and the remainder was wet sieved (0.5mm mesh size). The retained material, including the constituent fauna, was preserved in seawater formalin for subsequent analysis. In the laboratory, samples were examined microscopically, and all species were identified and counted.

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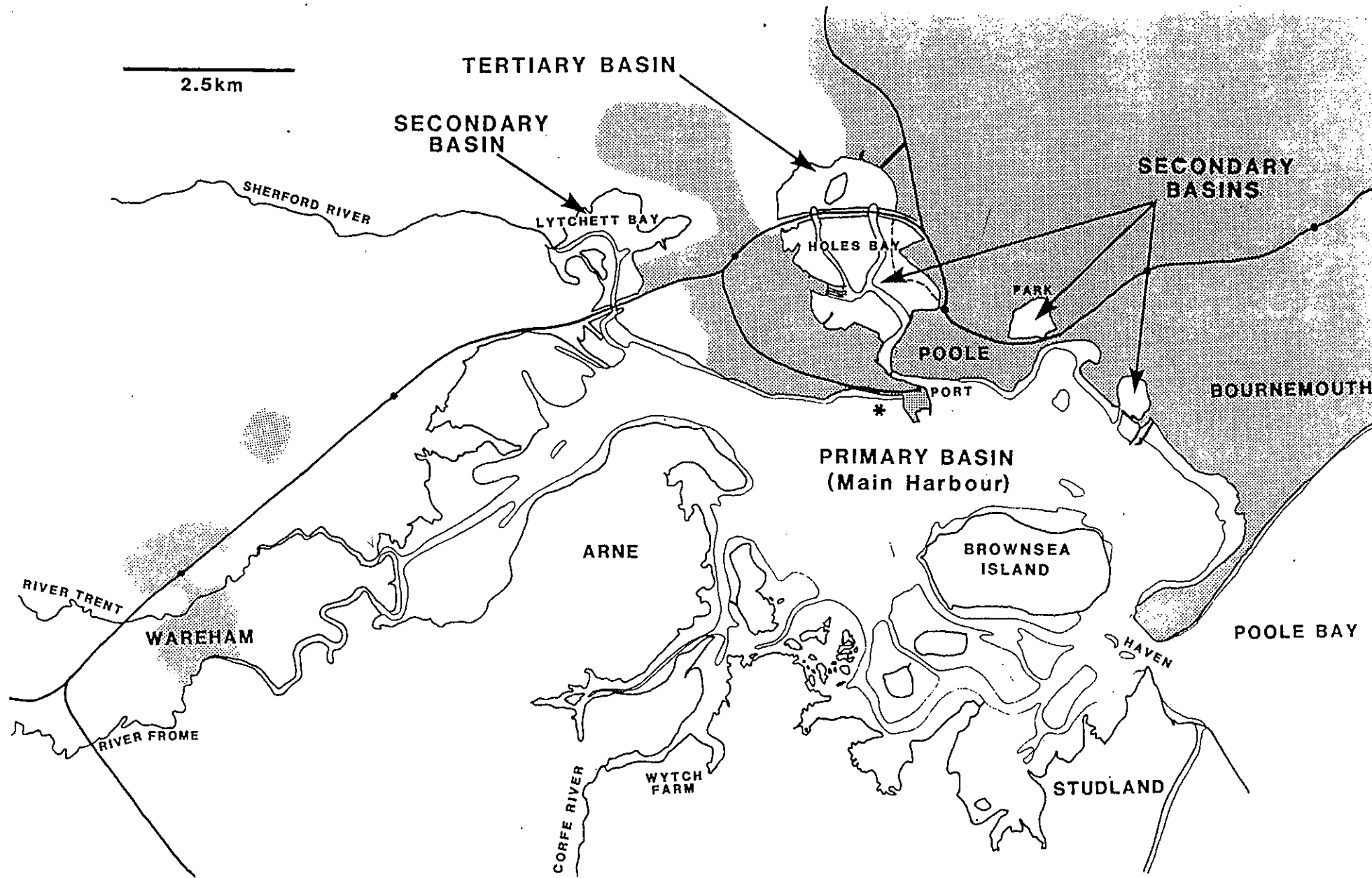


Fig.1. Structure of Poole Harbour as a network of interconnected basins. The primary basin is in communication with Poole Bay and the English Channel beyond, via a single link-channel - the Haven. Four secondary basins and one tertiary, have been artificially created along the north shore of the Harbour. \* Infill area for Port Expansion Scheme.

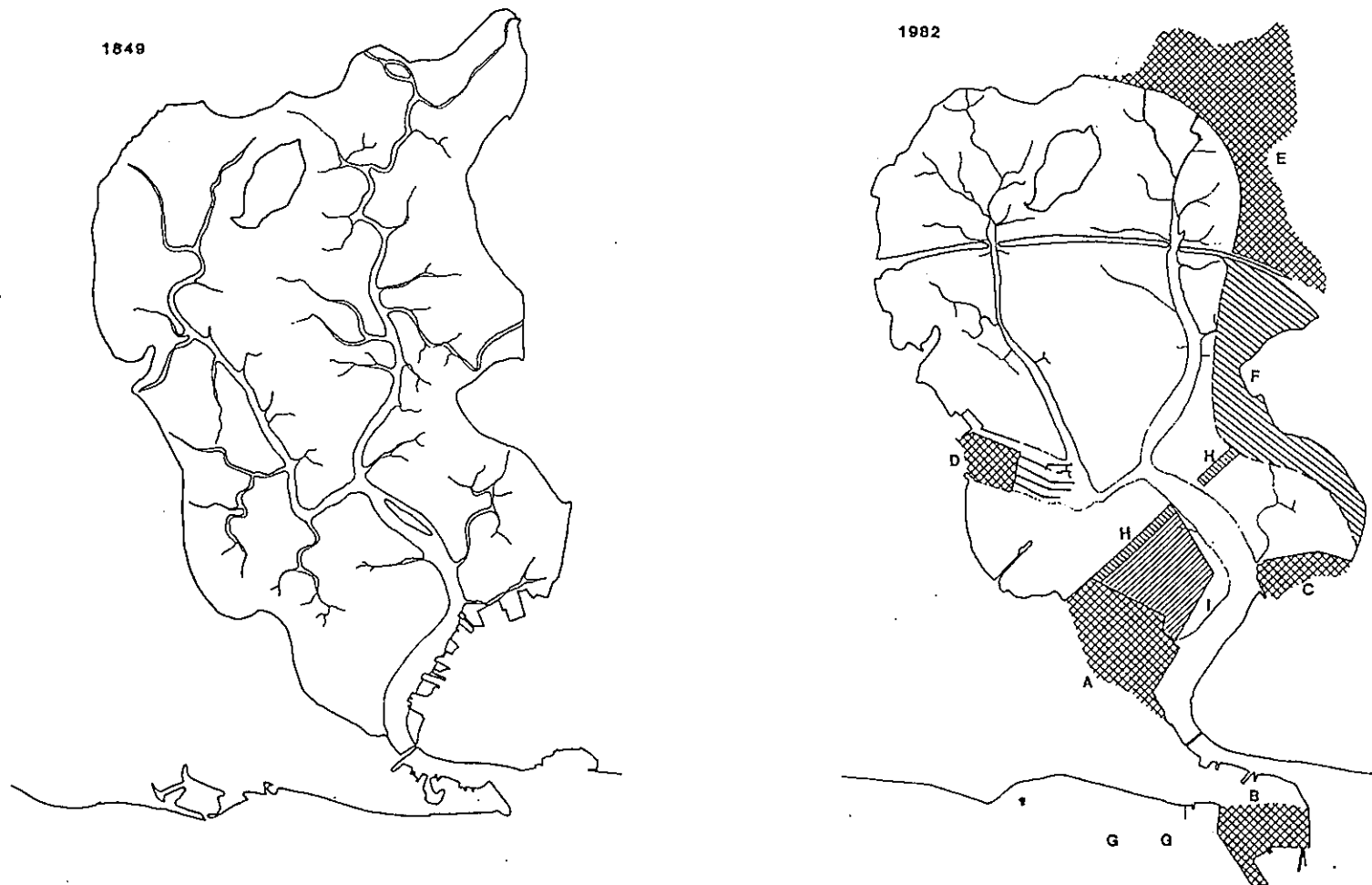


Fig.2.  
 Holes Bay. Changes in area and channel structure between 1849 and 1982.  
 2a) Shoreline and channel structure in 1849. Derived from the Hydrographic Chart prepared by Capt. Sheringham in that year.  
 2b) Shoreline and channel structure in 1982. This includes the extent of major infilling programmes completed up to this time, and other major programmes that are planned: Railway embankment (1880's); A - C.E.G.B. (1930's); B - Continental ferry terminal (1970's); C - R.N.L.I. (1970's); D - Marina (1970's); E - Route 9, phase 1 (1970's); F - Route 9, phase 2 (in progr. Feb.1983); G - Port Expansion; H - Route Y (1990's); I - Additional infilling (?). 1982 map based on P.H.C. hydrographic section charts, and on aerial photographs. Proposed infill outlines provided by Dorset County Council.

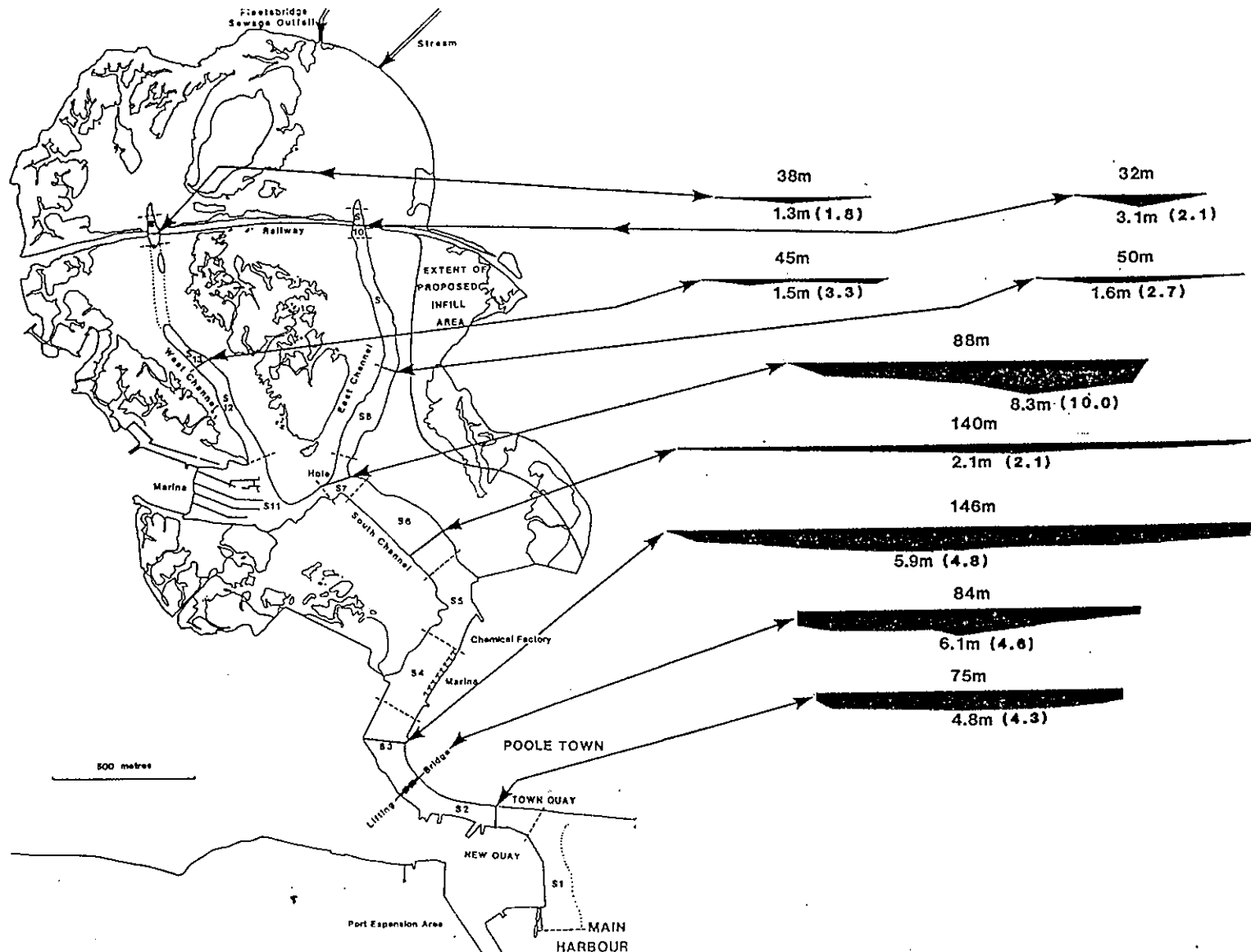


Fig.3  
 Holes Bay - General characteristics. Shoreline as of 1982, with route 9, phase 2 infill area demarkated. Extent of subtidal channel system, delimited by chart datum line. Channel profiles show bathymetric variations through the system. Channel width and maximum depth as of 1981 is shown for each profile (derived from the bathymetric data collected by P.H.C. Hydrographic Section), together with the maximum depth as of 1849 (in brackets, derived from the Hydrographic chart of Capt. Sheringham, 1849). The system has been divided into 14 sampling sections: S1-3 Outer Link-Channel; S4-5 Inner Link-Channel; S6-7 South Channel; S8-10 East Channel; S11-14 West Channel.

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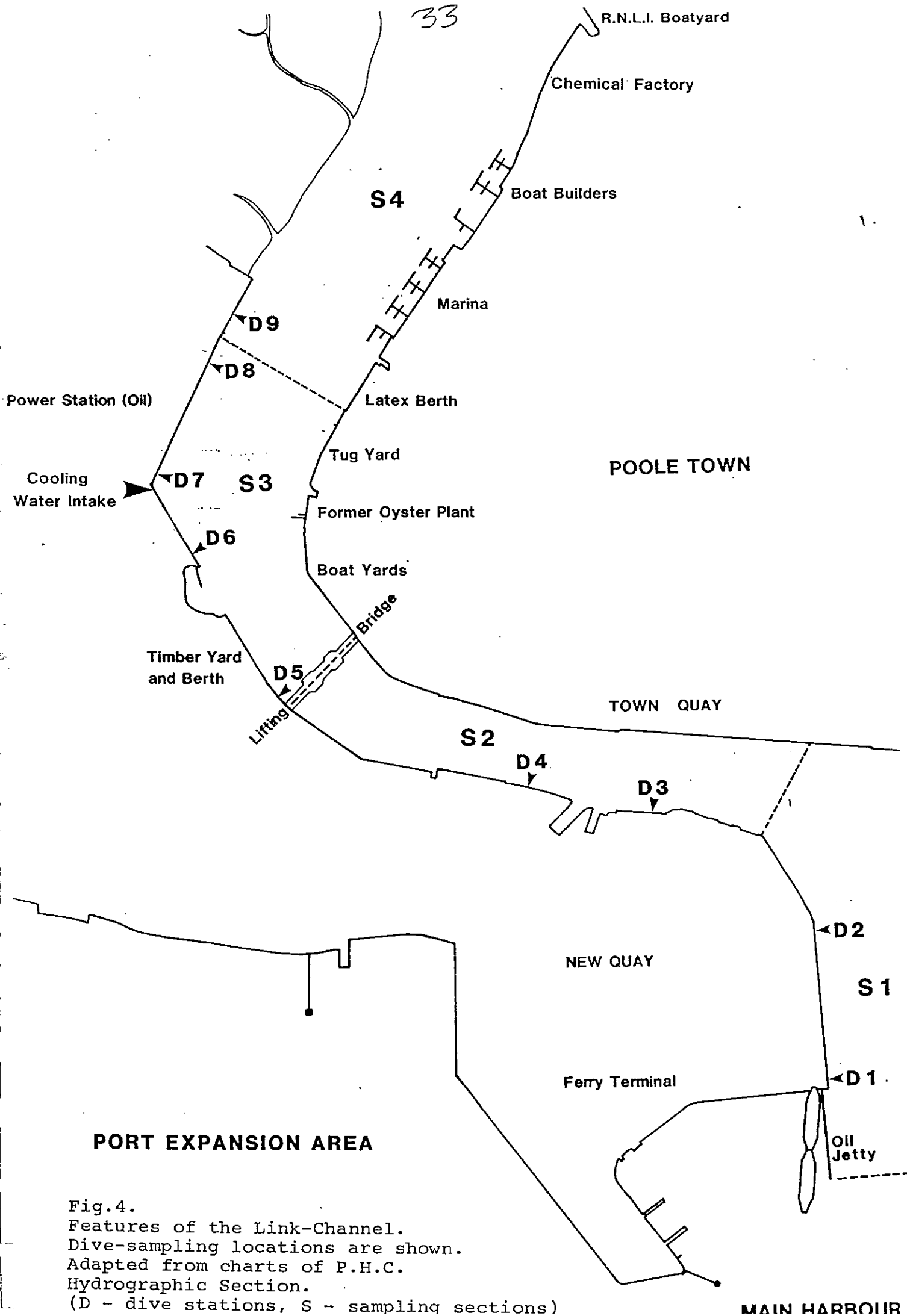
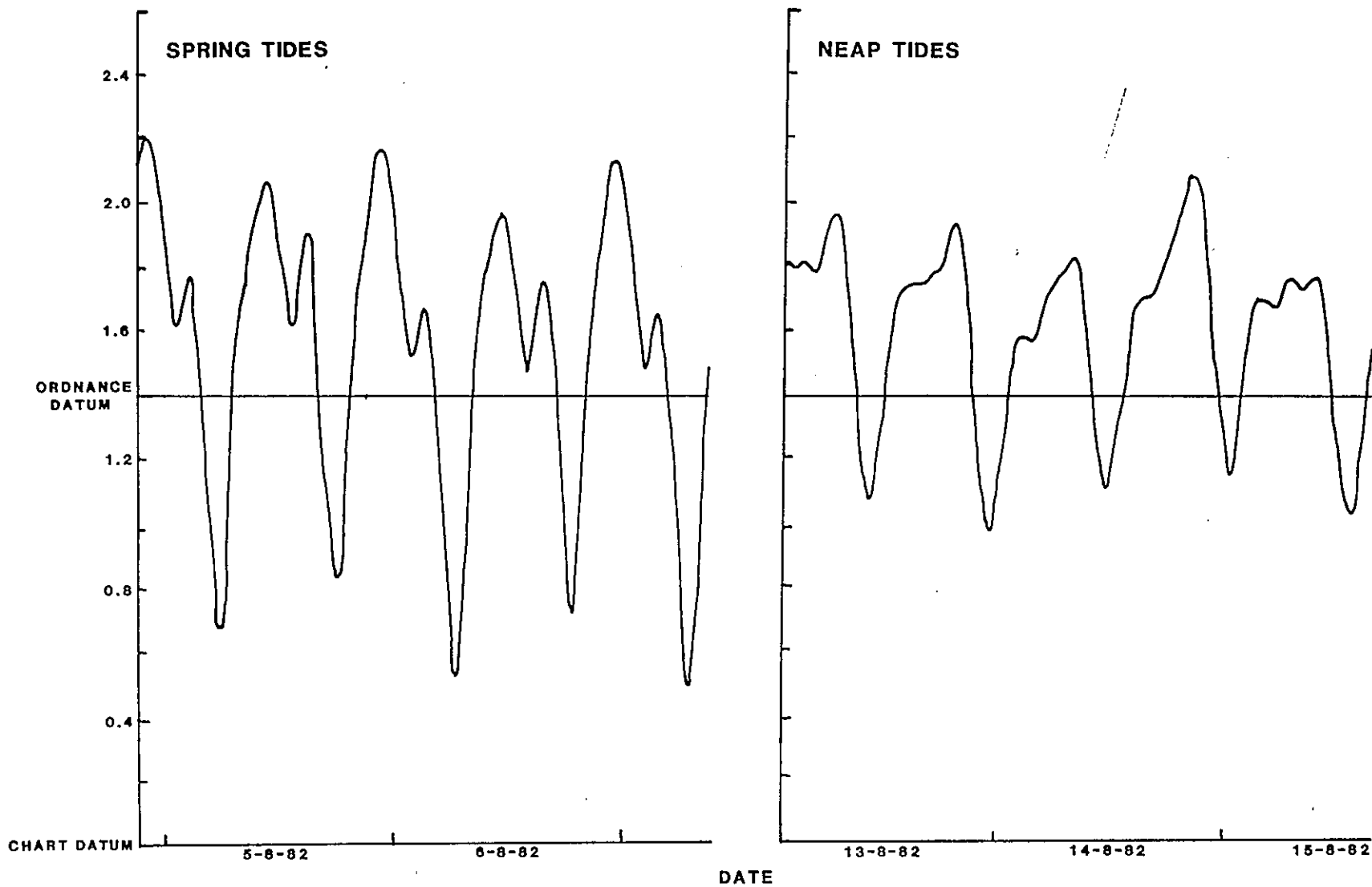


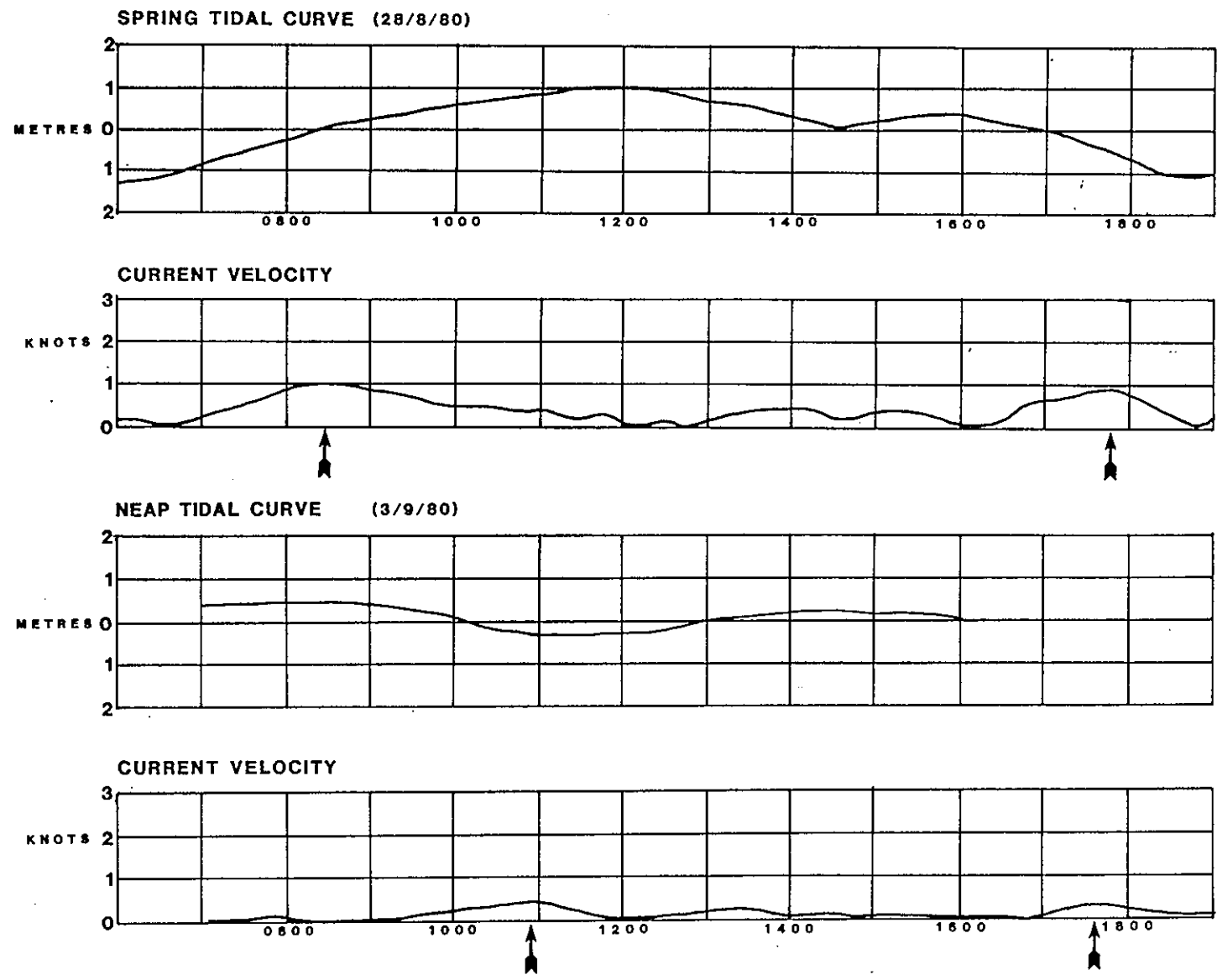
Fig.4.  
 Features of the Link-Channel.  
 Dive-sampling locations are shown.  
 Adapted from charts of P.H.C.  
 Hydrographic Section.  
 (D - dive stations, S - sampling sections)

MAIN HARROIR



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Fig.5. Comparison of spring and neap tidal cycles at Poole Town Quay. Data from permanent tide gauge maintained by P.H.C. Hydrographic Section.



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Fig.6. Variations in tidal velocity between spring and neap tides, in the central part of the Holes Bay subtidal channel system. Derived from data collected by P.H.C. Hydrographic Section, at a temporary current metering station in the South Channel, adjacent to the 1st crab station south of S7 - see fig.7.



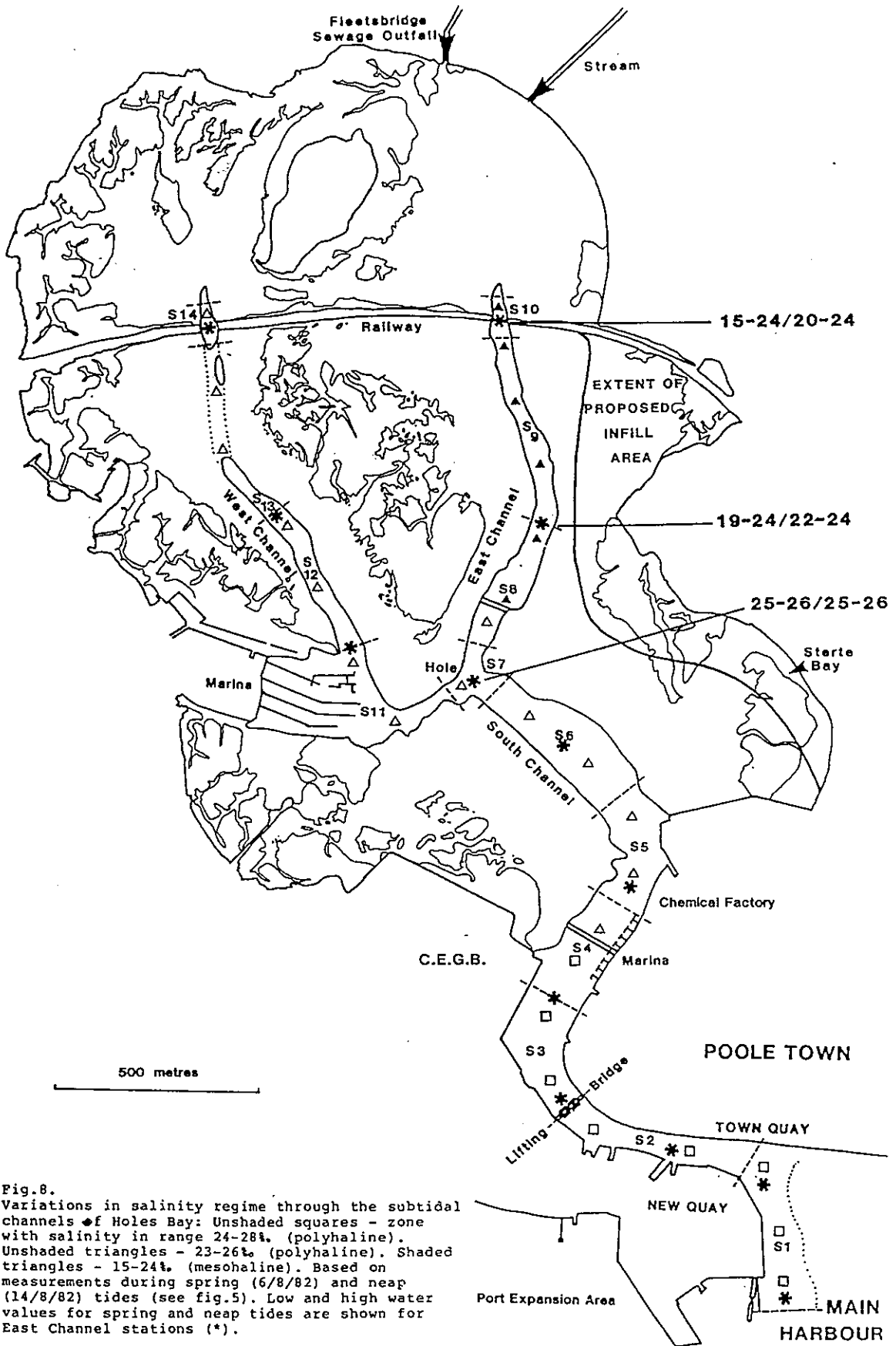


Fig.8. Variations in salinity regime through the subtidal channels of Holes Bay: Unshaded squares - zone with salinity in range 24-28‰ (polyhaline). Unshaded triangles - 23-26‰ (polyhaline). Shaded triangles - 15-24‰ (mesohaline). Based on measurements during spring (6/8/82) and neap (14/8/82) tides (see fig.5). Low and high water values for spring and neap tides are shown for East Channel stations (\*).

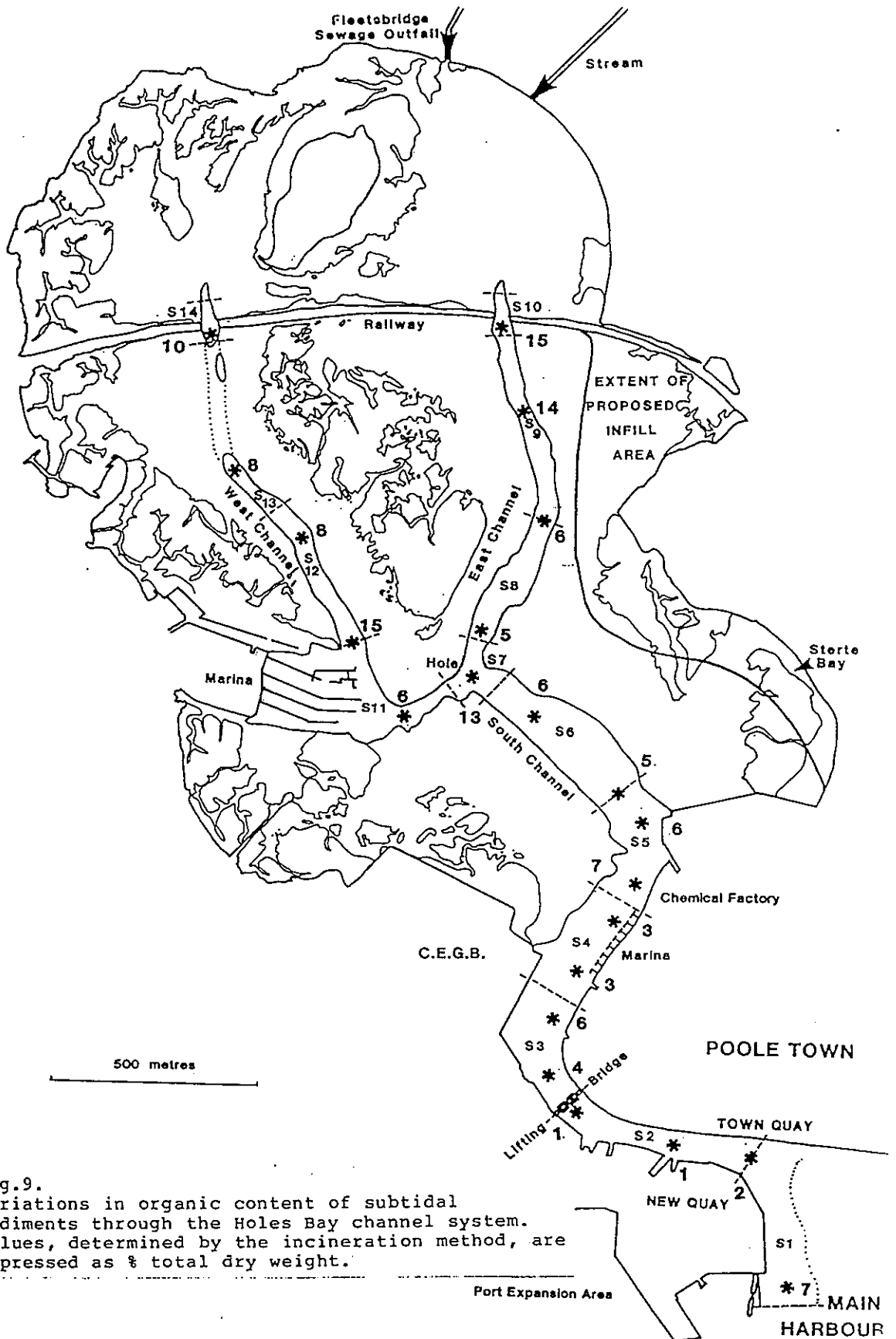


Fig.9. Variations in organic content of subtidal sediments through the Holes Bay channel system. Values, determined by the incineration method, are expressed as % total dry weight.

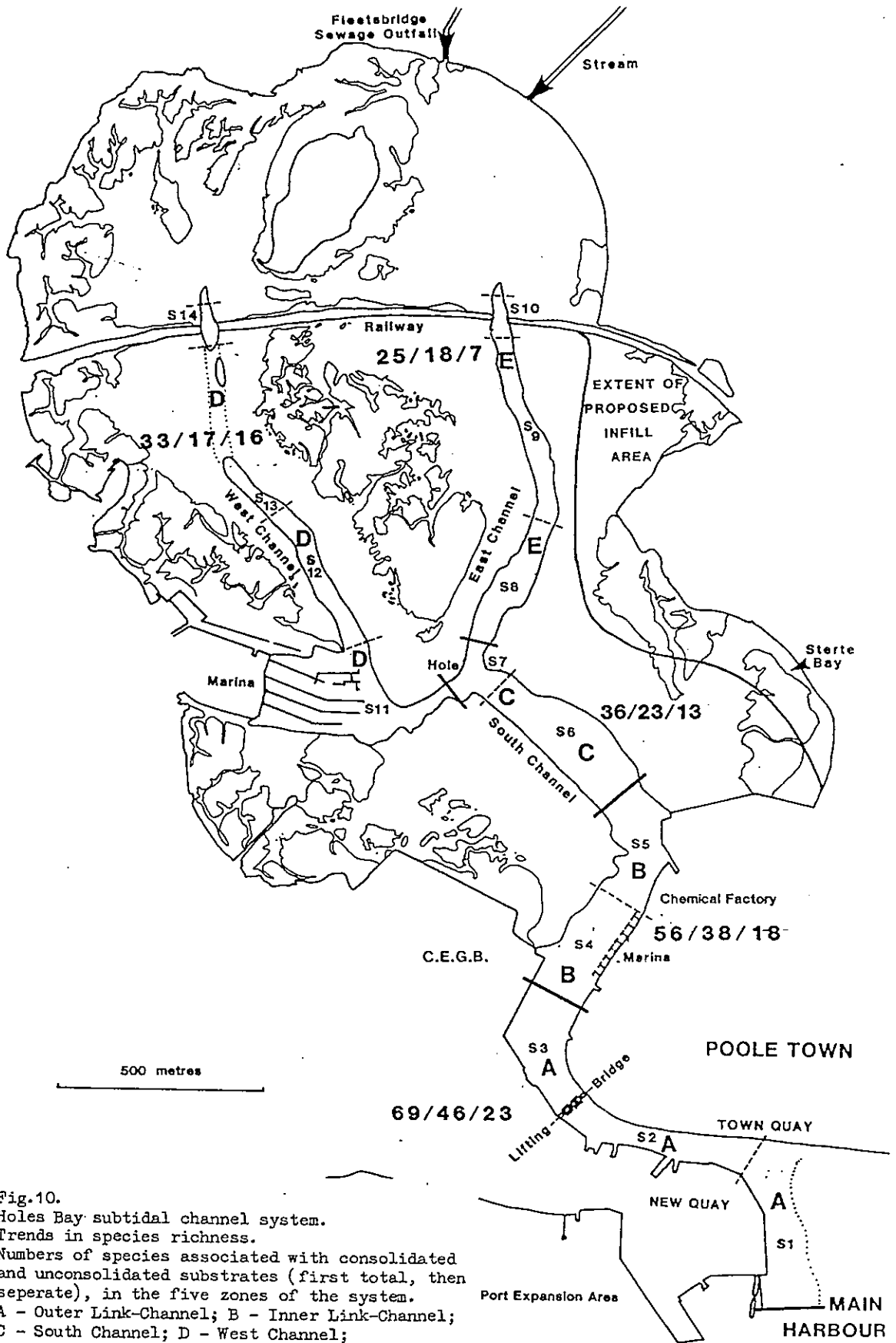


Fig.10.  
 Holes Bay subtidal channel system.  
 Trends in species richness.  
 Numbers of species associated with consolidated and unconsolidated substrates (first total, then separate), in the five zones of the system.  
 A - Outer Link-Channel; B - Inner Link-Channel;  
 C - South Channel; D - West Channel;  
 E - East Channel.

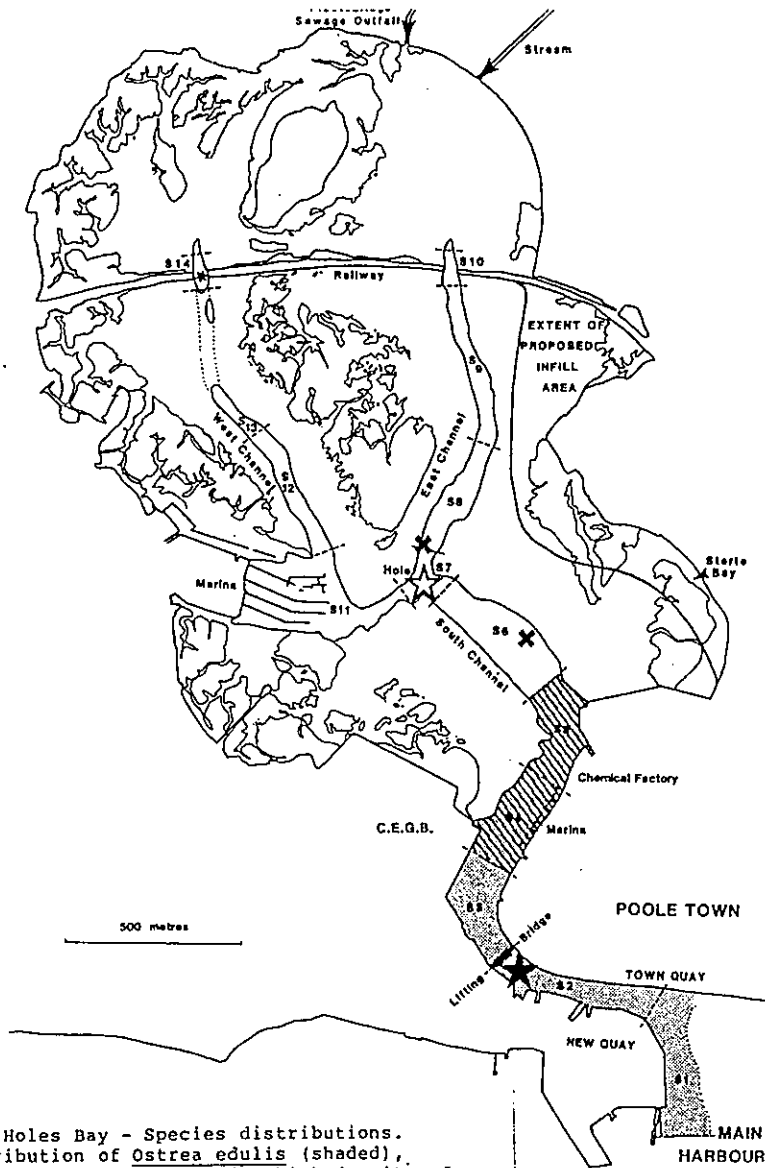
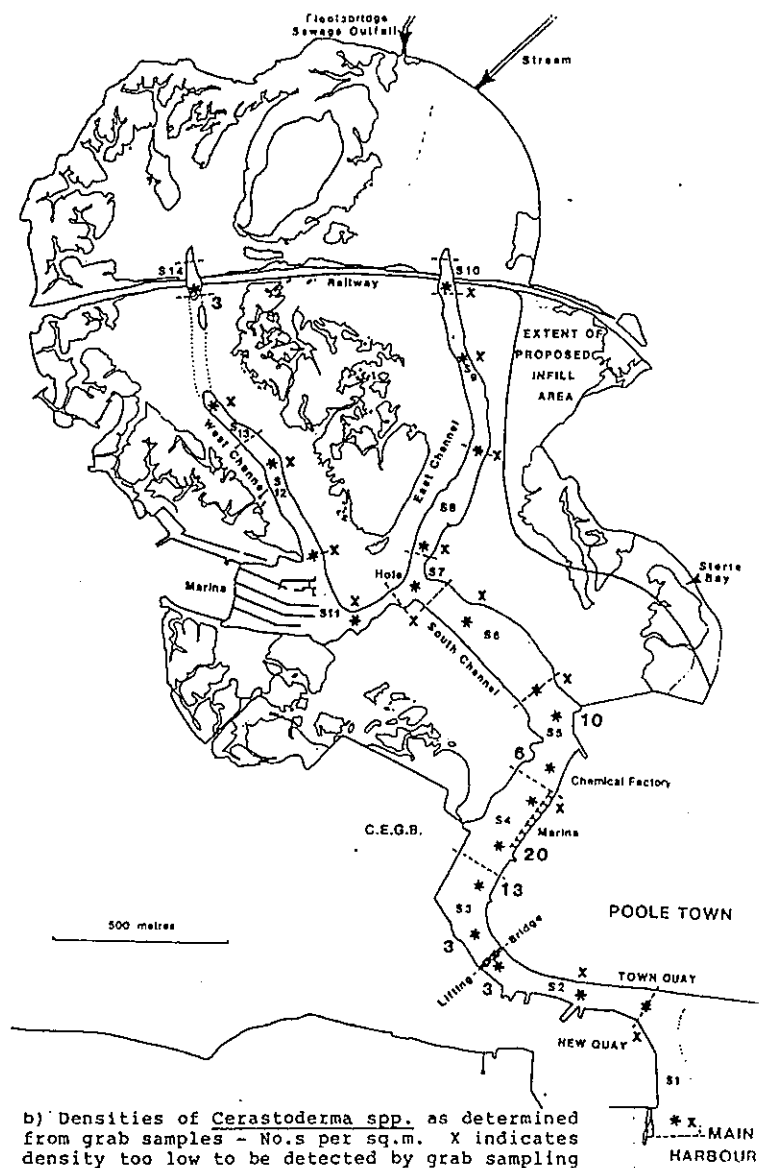


Fig.11. Holes Bay - Species distributions.  
 a) Distribution of *Ostrea edulis* (shaded), *Crepidula fornicata* (hatched), high density of juvenile flatfish (open star), *Urosalpinx cinerea* (shaded star), drift *Sargassum muticum* (crosses).



b) Densities of *Cerastoderma* spp. as determined from grab samples - No.s per sq.m. X indicates density too low to be detected by grab sampling programme, but detected by cockle dredge.

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