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8. Sub-tidal Ecology of Poole Harbour – An Overview

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Baseline surveys during the 1980s provided the first comprehensive information on the distributions and characteristics of habitats and epibenthic communities within the low water channels of Poole Harbour. Cross- and long-channel variation in habitats and species can be related to equivalent hydraulic gradients involving tidal currents. Dredge, grab and diving assessments collectively produced a species inventory of 68 seaweeds, 159 invertebrates and 32 fish. The best developed epibenthic communities with the greatest biodiversity occur in central areas of the harbour where tidal currents are relatively modest. Peacock Worm *Sabella pavonina* forests are the most significant of the communities found in the harbour, in the context of biodiversity. Human impacts are significant in terms of habitat loss and degradation, e.g. land reclamation, navigational dredging and pollution of various kinds. However, the huge presence and continued arrival of non-native species can be viewed as the most serious threat to biodiversity.

Introduction

Poole Harbour is a 3600 ha, near-land-locked tidal basin located on the central southern coast of England, featuring extensive shores and shoals of sand and mud, dissected and drained by a 35 km network of narrow tidal channels (Figure 1). Although essentially estuarine in character, the harbour also has lagoonal characteristics (Barnes, 1989).

Cotton (1914) considered the sub-tidal channels to be the most interesting feature of the harbour regarding seaweeds, and Waddington (1914) provided sub-tidal invertebrate records, making special mention of the Peacock Worm *Sabella pavonina* “that is to be found in vast numbers” in certain parts of the harbour. Collins and Dixon (1979) undertook the first detailed sub-tidal survey work, using dredging and diving to assess the distribution of oysters and some other conspicuous epibenthic (seabed surface-dwelling) species within an area destined for port expansion.

The need for comprehensive survey data on the harbour as a whole became pressing during the late 1970s and early 1980s as evidence of poor water quality and environmental deterioration coincided with rapid expansion of the Poole conurbation,

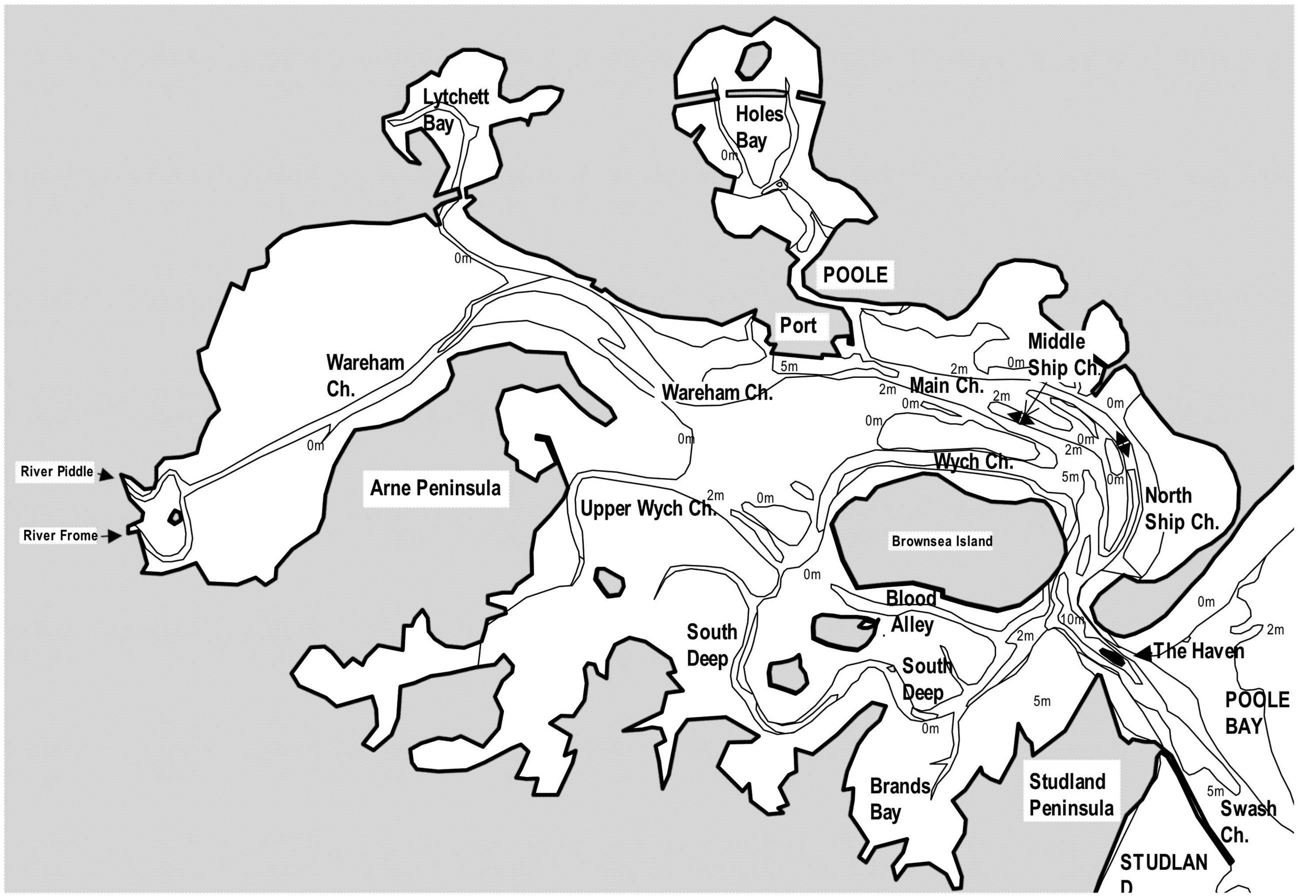

Figure 1 Poole Harbour showing the bathymetric regime evident at the time of the sub-tidal baseline surveys of the 1980s.

further land reclamation for port expansion, marinas, roads and other developments, plans for exploitation of a major oilfield discovered beneath the southern sector, and diversification and intensification of the shellfish culture industry.

In 1982, the sub-tidal channels within Holes Bay were surveyed systematically for the first time (Dyrynda, 1983), followed by those in the southern and northern sectors of the main harbour basin in 1984 and 1985, respectively (Dyrynda, 1985, 1987a, b). These surveys provided a baseline of information on sub-tidal habitats and communities. They revealed the existence of complex distributional patterns of substrates and epibenthos within the tidal channels, and provided indications of the environmental parameters that govern them.

More localized sub-tidal studies undertaken since have included EIA-related work in the South Deep, the port area and Holes Bay, and unpublished studies of the ecology of docks, marinas and farmed shellfish grounds (Dyrynda, 1988, 1989, 1994a, b and others).

In 2003, a new dredging survey was undertaken, covering most areas of the channel system, and providing the first opportunity to gauge ecological stability and change since the baseline surveys two decades earlier (Dyrynda, in prep.).

Howard and Moore (1989) reviewed existing knowledge of the harbour environment in the context of marine conservation, and Langston *et al*. (2003) have provided an up-to-date and detailed environment review, with a particular emphasis on environmental quality.

This chapter provides a synthesis and overview of the habitats and biological communities identified within the sub-tidal zone of Poole Harbour over recent decades, together with a brief analysis of the natural and human factors that influence them.

Methods

The 1982 Holes Bay sub-tidal survey involved channel-centre grab sampling to investigate sediments and infauna, long-channel dredge hauls to appraise larger epibenthic species, and diving to examine fouling assemblages on dock walls (Dyrynda, 1983). The 1984 and 1985 surveys of the main harbour basin involved dredge hauls at 130 locations and grab sampling at a proportion (Dyrynda, 1985, 1987a, b) (Figure 2).

Exploratory dredging at different points across selected channel profiles showed that bottom substrates and key epibenthic species are in many places localized in distribution. To examine these spatial patterns more systematically, 49 cross-channel dive transects were surveyed at points throughout the low water channel network (excluding Holes and Lytchett Bays) (Figure 2). For each transect, a diver swam the length of a survey line recording at 1 m intervals: (i) seabed depth; (ii) substrate and bedform; (iii) key

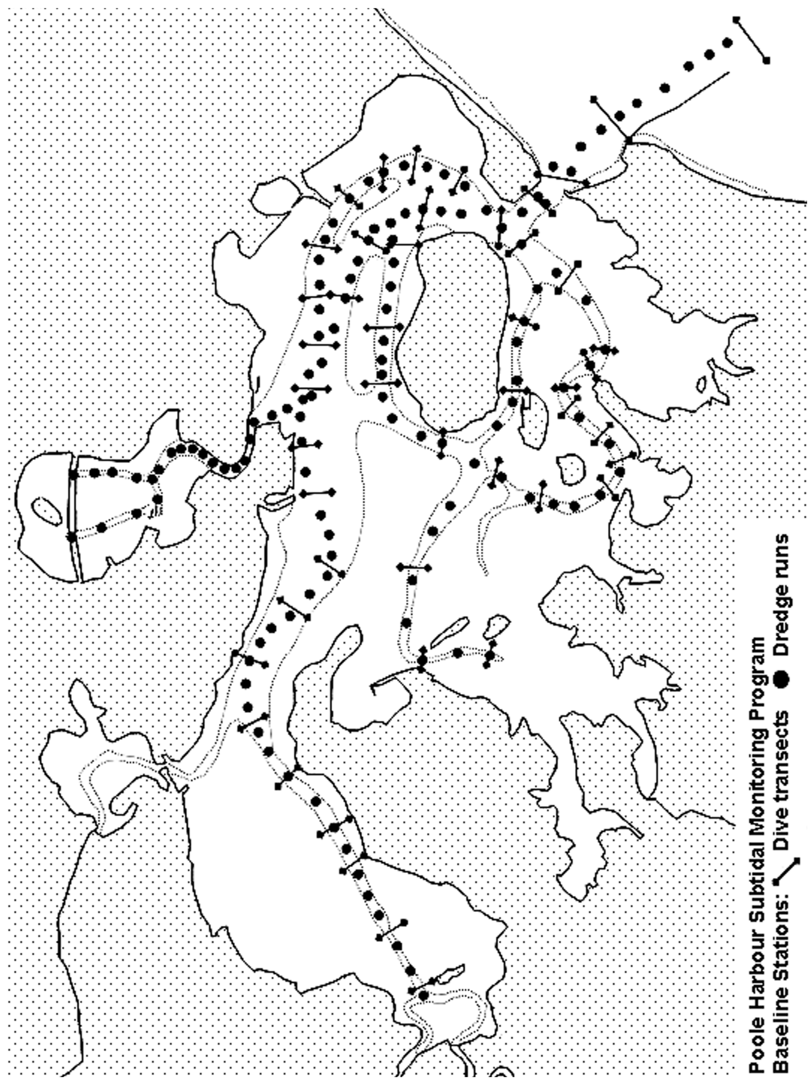

Figure 2 **Dredge and dive survey stations assessed during the 1980s baseline surveys.**

epibenthic seaweeds and invertebrates; (iv) evidence of human influence. The transects collectively covered more than 5000 m of channel bottom, ranging from the 15.6 m deep harbour entrance (spanned in entirety) to shallow areas less than 1 m deep within upper reaches. All surveys were undertaken during the summer months.

The 2003 dredging programme once again involved long-channel hauls undertaken at channel-centre throughout the harbour. Retrieved samples were sorted into species, an inventory was produced and some of the more abundant species were weighed.

Physical characteristics of Poole Harbour

The main harbour basin, which is broad in comparison with many estuaries contains five islands. Fresh water enters Poole Harbour through several small rivers and streams, the largest being the River Frome. All tidal exchange takes place through a single, narrow tidal inlet to the east flanked by a pair of sandy peninsulas (Figure 1). There are also two subsidiary basins to the north: Holes Bay and Lytchett Bay, which have become increasingly isolated as a result of land reclamation.

The tidal range is small (maximum ~ 2 m) and the cycle asymmetrical, with a double high tide producing prolonged high-tidal stands, followed by a rapid ebb. The salinity regime across much of the harbour is in the range 20–30‰ and quite stable both through the tidal cycle and seasonally, although the Wareham Channel and adjacent shores experience a lower and more variable regime (10–25 ‰).

The sub-tidal channels are generally shallow (mostly <5 m), although they are deepened locally as a result of enhanced tidal scour or navigational dredging (Figure 1). Tidal currents are generally in the 0.5–1 m s^{-2} range, although greater speeds are attained where flow is constricted, notably within the harbour entrance (maximum ~ 2.3 m s^{-2}).

Physical environment within sub-tidal channels – configuration and bathymetry

The main sub-tidal channel lineage extends from Poole Bar up the Swash Channel, Brownsea Roads, the Middle Ship Channel and the Wareham Channel to the mouth of the River Frome (Figure 1). Important subsidiary lineages include the South Deep and Blood Alley, the Wych Channel, the North Ship Channel and those draining Holes and Lytchett Bays (Figure 1).

The Admiralty Charts for Poole Harbour, bathymetric data from Poole Harbour Commissioners, and dive-transect results from the 1980s' baseline surveys all illustrate typical downstream increases in depth and cross-sectional area within each channel lineage, indicative of increasing tidal velocity, volumes and scour (Figure 1). Linear sections of undredged channel usually feature symmetrical profiles with gently sloping flanks. Localized, steep-flanked scour holes reflect increased erosion where tidal flow is concentrated, constricted or deflected, most often within channel bends where the cross-channel profile is typically skewed towards the outer, eroding flank (Figure 1).

Sections of channel subjected to regular navigational dredging are not only ‘over-deepened’ but also feature unnaturally geometric profiles. During the early 1980s, capital dredging was undertaken alongside land reclamation in the outermost Wareham Channel, to provide a deepwater turning basin for ferries and other vessels. Prior to 1987, the then Main Channel (now the North Ship Channel) was dredged periodically along much of its length. In 1987, capital dredging took place on Poole Bar and along the length of the former Middle or Diver Channel which has since replaced the North Ship Channel as the main navigation route.

Bottom substrates and bedforms

The dive transect baseline surveys of the 1980s revealed the existence of a broad spectrum of substrates across the sub-tidal channel network. In some areas, a succession of different substrates occurred across a single channel transect, whereas in others substrate diversity was low. The dive results also showed that the highest energy substrata typically occur at channel-centre within linear sections of channel, and towards the outer, eroding flanks within channel bends (Figure 2). For example, within the narrowest section of the harbour mouth, medium sand occurs along the channel peripheries, grading down-slope through coarse sand and gravel, to an outcrop of hard clay and adjacent accumulations of rough cobbles and oyster shells within the deepest section. A little further upstream, the eroding eastern flank of Brownsea Island features a steep slope of hard clay, and outcrops of hard ‘ironstone’.

The outermost bend within the South Deep featured fine to medium sand upon the inner, depositing flank, A steep slope of hard clay formed the outer, eroding flank. The channel floor was dominated by a Peacock Worm forest.

Data combined for all dive transects show a general upstream-downstream shift from low to high energy substrata, in all channel lineages (Figure 3). Soft mud plains dominate upstream-most sections, whereas coarse sediments (coarse sand, gravel, cobbles), exposures of hard clay and locally, hard bedrock prevail in downstream-most areas. Trains of mobile quartz sand and gravel waves orientated perpendicular to the axis of tidal flow were observed within the lowest sections of the Wych and Middle Channels. Waves observed locally within the middle reaches of the Wareham Channel were composed of mollusc shell gravel.

Fine to medium sands dominate intermediate sections of every channel lineage, often augmented by veneers or scatterings of the shells of smaller molluscs. The species involved vary from area to area. Slipper Limpet and cockle shells are most common within more downstream areas, and shells of the Gaper *Mya arenaria* prevail within the upper reaches of the Wareham Channel.

The combined dive transect data also revealed a south-west to north-east gradient across the harbour of increasingly coarse sediments, that may reflect increased exposure to wave action (with increasing ‘wind fetch’) (Figure 3).

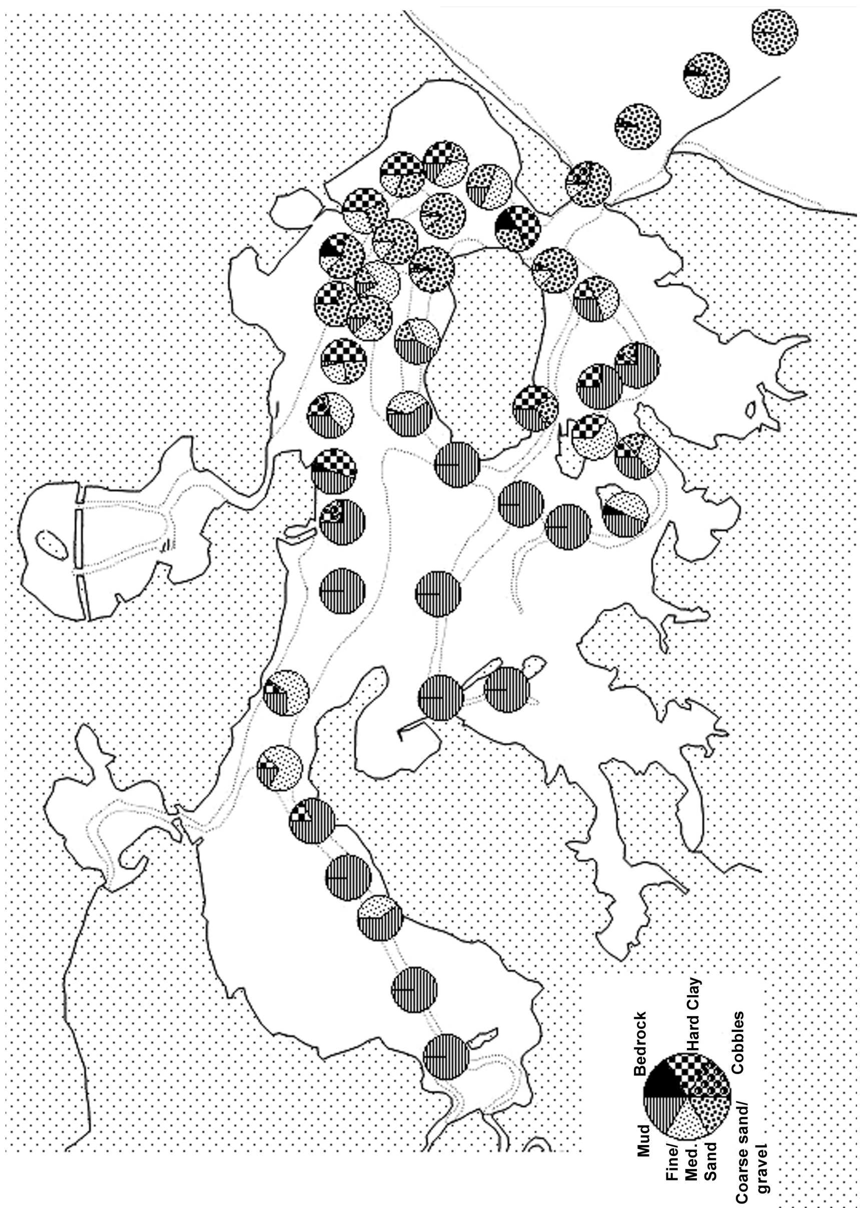

Figure 3 Harbour-wide distribution derived from dive transect data: bottom substrates.

Figure 4 Harbour-wide distribution derived from dive transect data *Sabella pavonina* forests.

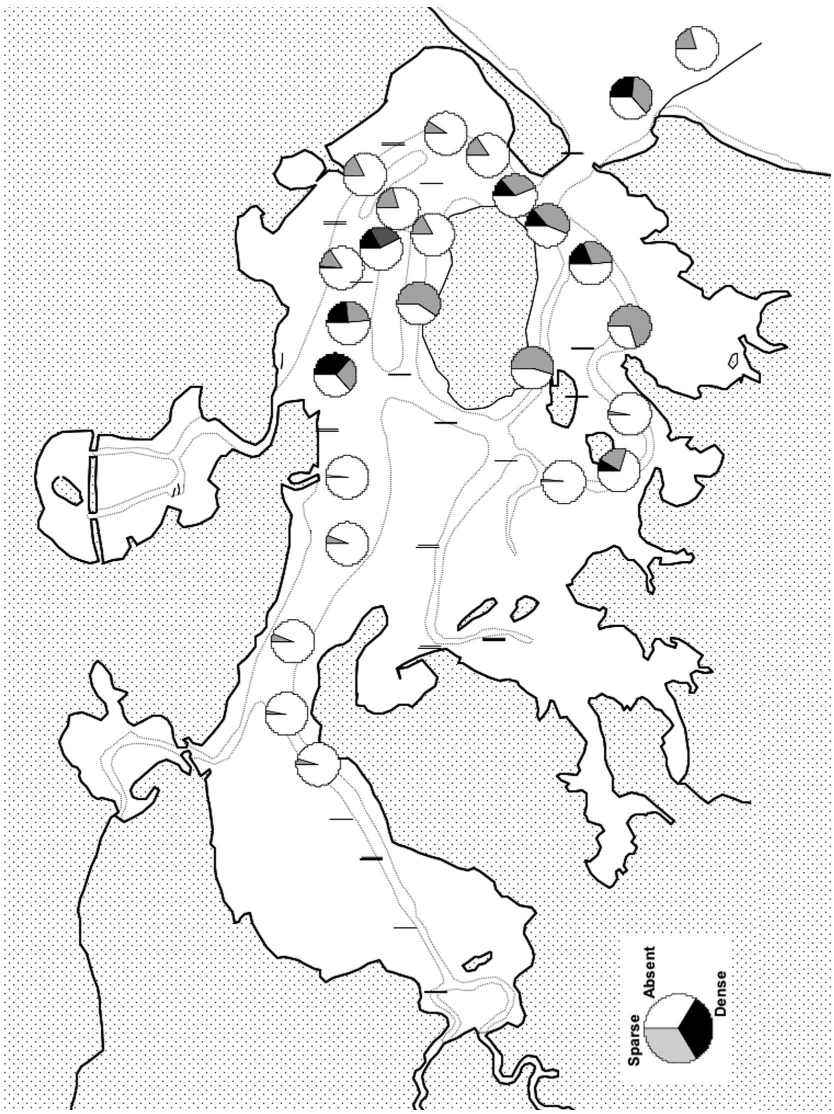

Figure 5 Harbour-wide distribution derived from dive transect data: *Crepidula fornicata*.

Epibenthic communities

Baseline survey results show that the potential for the development of epibenthic communities is influenced by the substrate, bedform and sediment transport induced by tidal currents, in addition to the salinity regime.

In upstream areas, the softness of the sediment and high rates of fine particle accretion are limiting factors. Within current-swept downstream areas, cobbles, stones and oyster shells are liable to be mobilized, and the bed-load transport of sand and gravel can exert severe abrasion pressure. The muds and fine to medium sands characteristic of intermediate tidal energy sections of the channel system proved most favourable for the development of epibenthic communities.

Upstream channel sections

Upstream sections of channel floored by soft mud were found to be largely or wholly devoid of epibenthic macrobiota (seaweeds or invertebrates). Numbers of Common Eel *Anguilla anguilla* burrows were observed within some areas of the channel system.

Mid-stream channel sections

Turbid water assemblages dominated by silt-tolerant invertebrates

Characteristic assemblages of silt-tolerant species were identified towards the top of the zone of epibenthos domination within every channel lineage. Tracts of mud and mud/sand mixtures supported well-separated ‘islands’ of epibenthic invertebrates including the introduced Korean Sea Squirt *Styela clava*, large growths of the sponges *Cliona celata*, *Haliclona oculata* and *Suberites massa*, and the bryozoan *Anguinella palmata* (Figure 6).

The first European record for *S. clava* was from Plymouth in 1953. It has since spread to many north-east European coasts, as a fouling organism and in association with translocated shellfish (Eno *et al*., 1997).

Peacock Worm Sabella pavonina forests

The Peacock Worm *Sabella pavonina* was found to form unusually dense and extensive forests within the channels of Poole Harbour (Figure 4). These prevail downstream of the ‘turbid water’ assemblages. Particularly well-developed forests were found in the South Deep and the Wych Channel. They occur on channel flanks where tidal currents are relatively strong, and on the central channel bottom where currents are more modest.

An adult tube may attain a length of 40 cm, at least half being embedded in sediment. Diving observations showed that fine sediment often settles within these forests, in places forming mudbanks 0.5 m or more in thickness.

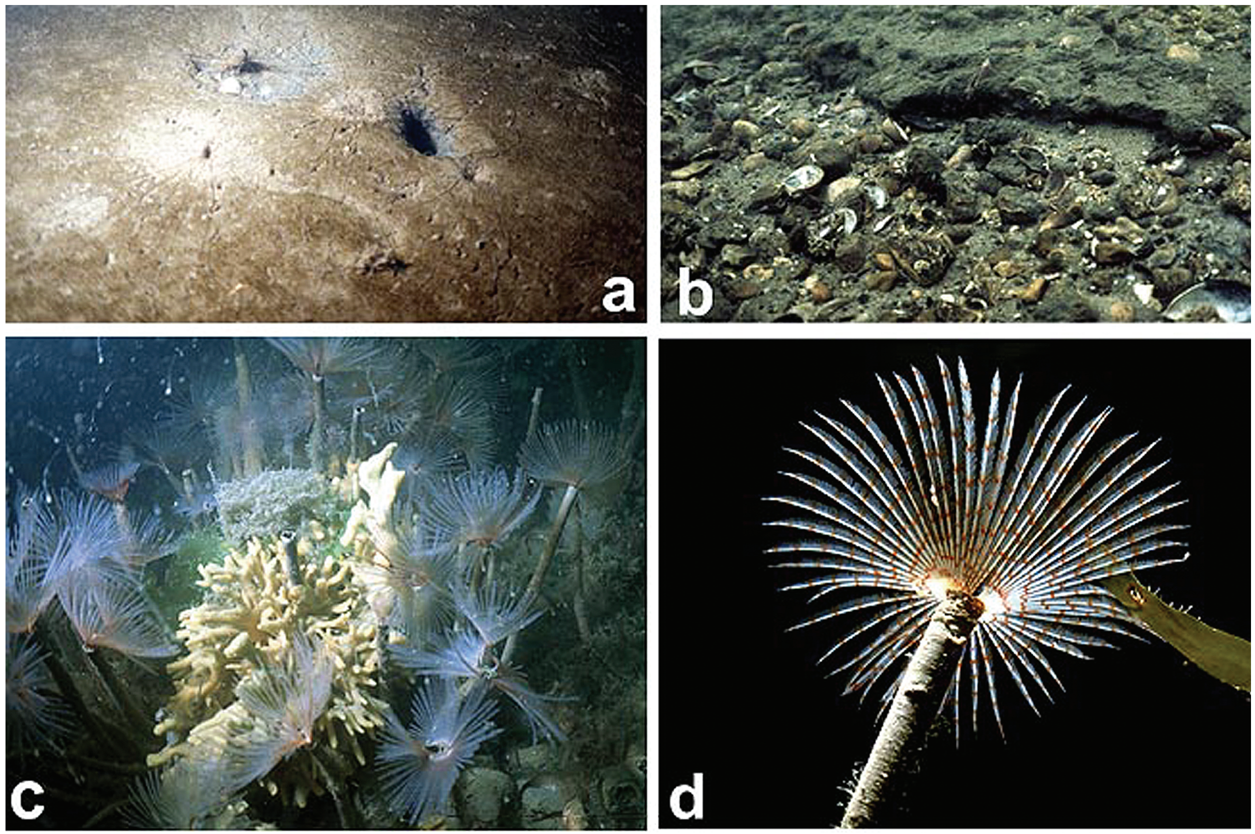

Figure 6 Some important habitats and epibenthic species found in Poole Harbour. (a) Mudbed with eel *Anguilla anguilla* burrows, Upper Wych Channel. (b) Tide scoured hard clay and cobbles, Haven Channel. (c) Peacock Worm *Sabella pavonina*. forest with the sponge *Halichondria bowerbanki*. (d) Tentacle crown of *Sabella*. (Figure 6 continued overleaf)

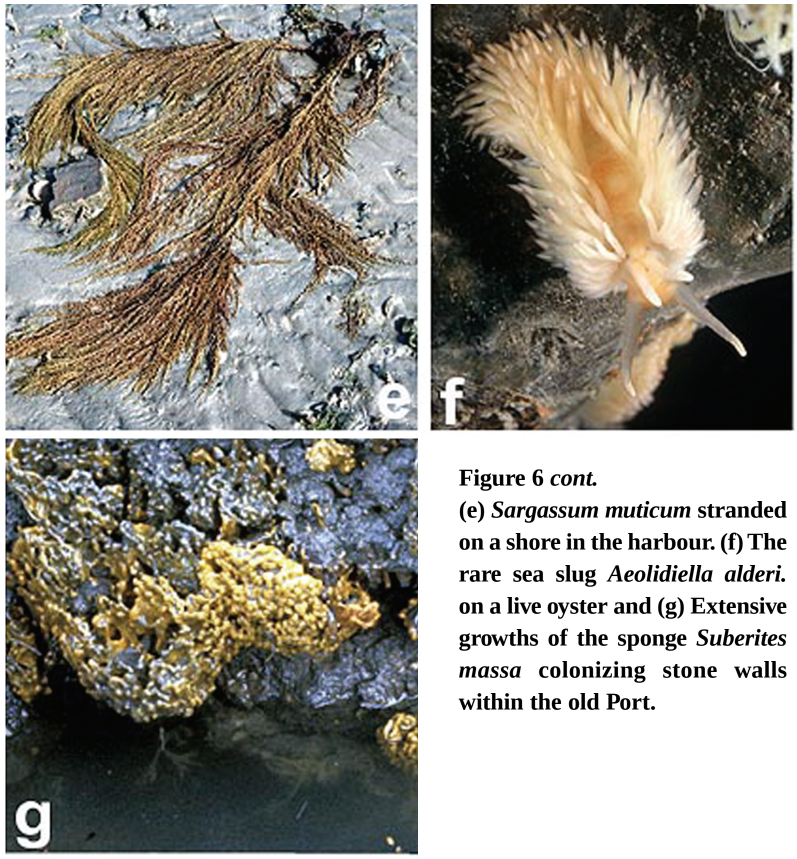

Figure 6 *cont.*
(e) *Sargassum muticum* stranded on a shore in the harbour. (f) The rare sea slug *Aeolidiella alderi.* on a live oyster and (g) Extensive growths of the sponge *Suberites massa* colonizing stone walls within the old Port.

Emergent parts of worm tubes are often colonized by red seaweeds, the sponge *Halichondria bowerbanki*, or clusters of the sea squirt *Ascidiella aspersa*. A multitude of subsidiary seaweeds, invertebrates and fish are also typically present within the *Sabella* forests.

Slipper Limpet Crepidula fornicata beds

The baseline dive transect and dredging baseline surveys identified the widespread occurrence of beds of *Crepidula fornicata* clusters within the low water channel system (Figure 5). Pioneer individuals can colonize various small hard substrates, but subsequent recruits often settle upon established individuals, so forming clusters. The maximum number of limpets observed within a Poole cluster is 27.

High-density limpet beds were found to be widespread towards the downstream end of the intermediate tidal energy zone. The dredge surveys also identified smaller beds within more upstream sections of all channel lineages, where tidal currents and scour are enhanced locally. Limpets were recorded upon a variety of substrata including firm mud, fine to medium sand and hard clay, on level bottoms or within scour holes, but not within the harbour mouth where currents are exceptionally strong.

The Slipper Limpet is a native of the north-east coast of North America. It is believed to have been introduced to UK waters about 1890 on ship hulls and translocated American Oysters *Crassostrea virginica* (Eno *et al*., 1997).

Sargassum muticum and other seaweeds

Baseline surveys identified large copses of *Sargassum* within the outer harbour, along the margins of the lower South Deep, Wych and Middle Channels, and across the channel bottom within the much shallower Blood Alley. Plants typically grow attached to small hard substrates such as cobbles or the shells of dead or live molluscs.

Field observatons have shown that *Sargassum* plants are routinely transported around the channel system, and in and out of the harbour by tidal currents, particularly during summer months when fronds can attain lengths of several metres. Many mobilized plants drag their anchoring substrates with them, whereas others drift after becoming detached.

Sargassum muticum was first recorded in the UK in the Solent in 1973 (Eno *et al*., 1997). It was first observed in Poole Harbour in 1979 (personal observation). Other seaweeds encountered frequently within the clearer waters of the outer harbour (in the 1980s and 2003) included *Polysiphonia elongata*, *Gracilaria* spp. and *Dictyota dichotoma* (notably within the lower Wych Channel and Blood Alley). The 2003 dredge survey also identified large quantities of a species of sea lettuce *Ulva rigida* across much of the harbour. During the 1980s, it was only found in quantity in the outermost South Deep.
Three previously unrecorded non-native species were also discovered. The red seaweed *Aghardiella subulata* was found in quantity in the South Deep, Blood Alley, Wych Channel and the outer Wareham Channel. It is thought to have arrived in the Solent area prior to 1973 (Eno *et al*., 1997). *Gracilaria doryhora* was found in the Upper South Deep. This species was first encountered in the UK in 1969 (Eno *et al*., 1997).

Mature specimens of Wakame *Undaria pinnitifida* were recorded at two locations within the lower Wych Channel in 2003. This large, invasive brown seaweed is of north-east Pacific origin. It was first found in the Poole Harbour area in March 2004 as drift specimens stranded in Shell Bay, and growing attached to floating docks within one harbour marina (personal observation). A substantial build-up of this species seems likely. The first UK record was from the Hamble estuary in 1994, and *Undaria* has since expanded its range and abundance considerably since that time (Eno *et al*., 1997; Fletcher and Farrell, 1999).

Downstream channel sections – tide-swept communities

Substrata within the most tide-swept sections of the channel system in and around the harbour entrance support an impoverished community characterized by scour-tolerant forms. Within one area, scour and abrasion are extremely intense, and boulders embedded in gravel were polished smooth, and barren. Elsewhere, cobbles and oyster shells supported low-drag, abrasion- and impact-resistant species; typically heavily calcified invertebrates such as the tube worm *Pomatoceros lamarcki*, the barnacle *Balanus crenatus* and the encrusting bryozoan *Cryptosula pallasiana*, and characteristic higher-drag species such as the hydroid *Hydrallmania falcata* and the bryozoans *Walkeria uvae*, *Alcyonidium diaphanum* and *Flustra foliacea*.

Localized accumulations of rough cobbles were found to be sufficiently stable to support larger, higher drag species, e.g. *Sargassum muticum* on one flank of Stone Island, and unexpectedly, a sparse cover of Peacock Worms within the deepest section of the harbour mouth.

Hard clay was generally free of attached species, but was in places bored by the North American Piddock *Petricola pholadiformis*. This species is thought to have arrived in the UK from North America before 1890 (Eno *et al*., 1997).

High energy coarse sand and gravel plains and also wave trains within and beyond the harbour were largely free of epibenthos apart from quantities of drift algae deposited on the bottom during slack tide periods, especially *Sargassum muticum* and *Laminaria saccharina* (Figure 6). Motile species encountered in these areas included the Hermit Crab *Pagurus bernhardus*, the Harbour Crab *Liocarcinus depurator*, the Common Cuttlefish *Sepia officinalis* and the Lesser Sand-eel *Ammodytes tobianus*.

Humanized environments

Dredged shipping channels

Recently dredged areas within the North Ship Channel and outermost Wareham Channel were found to be largely barren, apart from scattered biota rafted in by tidal currents. At one North Channel location, fragments of a Peacock Worm forest were evident, dissected by dredge-excavated trenches.

A dive transect spanning the Main Channel assessed one day after grab dredging, revealed relatively intact tracts of channel bottom with associated epibenthic seaweeds and invertebrates interrupted by ‘barren’ dredge craters.

The 2003 dredge survey was of interest in the context of recovery after navigational dredging. The survey revealed a substantial presence of Slipper Limpets in the North Ship Channel colonized by the sea squirt *Ascidiella aspersa* (dredging ceased around 1987).

Natural and farmed oyster beds

During the baseline surveys of the 1980s, and also the 2003 re-appraisal, numbers of 'wild oysters' in the sub-tidal channels were found to be low, with sporadic 'ones and twos' being typical of hauls in favourable areas (apart from high densities encountered where stock had been deposited within leased grounds).

Diving observations indicate that intensive shellfish dredging can have a significant impact on channel bottom sediments and biological assemblages. Shellfish dredges typically retain a substantial by-catch of non-target algae and sedentary invertebrates (hence their value for survey work).

Sub-tidal shellfish grounds are usually cleared of 'undergrowth' before laying new stock. This process usually mobilizes fine sediment, exposing previously buried shell material and coarse sediment fractions at the surface.

At the time of the baseline surveys, Solent oysters deposited in the South Deep were found to be colonized by the sea squirt *Dendrodoa grossularia*, which does not occur naturally in the harbour. Monitoring of deposited oysters and their epibionts in 1988–89 showed that *Dendrodoa* and other fully saline species died-off progressively and were replaced by colonizers typical of the harbour. History has shown that oysters can serve as Trojan horses for diseases and non-native species, and short-distance translocations can play an important role in the shuttling of alien species around a region, whereas long-distance translocations (trans- or inter-oceanic) can lead to totally new species introductions (Eno *et al*., 1997).

Baseline surveys and other studies conducted on leased grounds suggest that farmed native oyster beds can become biodiverse. The Sulphur Sponge *Cliona celata* and the tubeworm *Polydora ciliata* often burrow into the shells of oysters. The sea anemone *Cereus pedunculatus*; the Keel Worm *Pomatoceros triqueter*, barnacles (including the non-native *Elminius modestus*), bryozoans (particularly *Conopeum reticulum* and *Cryptosula pallasiana*) and sea squirts (particularly *Ascidiella aspersa* and the Korean Sea Squirt *Styela clava*) adorn the shells of live and dead oysters, and a variety of small crabs and fish use gaping shells as refuges.

A population of the rare sea slug *Aeolidiella alderi* was identified on an experimental oyster plot west of Brownsea Island. Individuals were seen consuming sea anemones and laying their eggs upon oyster shells (unpublished observation).

Docks and marinas

The port area and small vessel marinas contain a variety of seawalls, jetties, floating docks, buoys and fixed channel markers, which provide good substrates for colonization by seaweeds and invertebrates. The sponge *Suberites massa* occurs in large numbers upon submerged dock walls within the channel leading into Holes Bay (Figure 6). This population is probably the most substantial found in UK waters. Other common organisms include the sponges *Halichondria bowerbanki*, *Haliclona oculata* and *Microciona atrasanguinea*, the sea anemone *Metridium senile*, the barnacle *Elminius modestus* and the Korean Sea Squirt *Styela clava.*

Marina pontoon floats and the unprotected hulls of vessels support assemblages that are significantly different to those found on fixed structures. Typical species include *Sargassum muticum*, the sponge *Sycon ciliatum*, the sea squirts *Botryllus schlosseri* and *Clavelina lepadiformis* and the non-native bryozoan *Tricellaria inopinata*, a Pacific species first recorded in Poole Harbour in 1998, representing only the second North Atlantic record (Dyrynda *et al.*, 2000).

Discussion

The dive transect method devised for the 1980s baseline surveys of the Poole Harbour proved very effective for the rapid assessment of the distributions of substrates, bedforms and epibenthic assemblages in relation to bathymetry. The role of hydraulic forces in governing the distribution and nature of epibenthic assemblages in coastal waters is well recognized (Hiscock, 1983), although the information gathered by this study on small-scale patterns within estuarine channels is relatively novel. The same is true of the identification of miniature equivalents to substrate regimes and bedforms normally associated with tide-swept, offshore shelf sea environments, e.g. sand and gravel waves and ribbons (Stride, 1982).

Biodiversity

Comparisons of the biodiversity (measured as species-richness – the number of species) of harbours and other marine inlets in southern Britain indicate that Poole Harbour is less diverse than certain fully saline inlets in Devon, Cornwall and Pembrokeshire, but more diverse than many others (Howard and Moore, 1989; Davidson *et al*., 1991). The combined dredge, grab and dive transect baseline survey revealed the presence of 68 seaweed species, 159 invertebrates and 32 fish (Dyrynda, 1987 a, b). The list is significantly different to the inventory compiled by Mallinson *et al*. (1999) during their long-term artificial reef studies in the fully saline waters of Poole Bay.

Peacock worm forests have been identified as ‘biodiversity hot spots’ within the harbour. *Sabella pavonina* is a widespread and common species in British coastal waters, but densities are generally low. The dense and extensive aggregations in Poole Harbour are exceptional. An abundant food supply in the form of organic detritus descending from the saltmarshes and other intertidal habitats, combined with moderate to strong tidal currents (enhancing the volume of water filtered), and extreme shelter from wave action are perhaps responsible for these forests.

Biological productivity

Poole Harbour is a highly productive environment, with prolific growth of seaweeds and saltmarsh plants generating a favourable food supply for a multitude of deposit and suspension-feeding invertebrates inhabiting shores, shoals and channels, including harvested clams, cockles, mussels and oysters, but also sponges, Peacock Worms and sea squirts. This production also passes through the food web to higher consumers including fish and shore birds of conservation and/or economic significance.

Rare species

Howard and Moore (1989) drawing on species lists produced during previous baseline surveys highlight the sponge *Suberites massa* and the bryozoans *Anguinella palmata*, *Farella repens* and the sea slug *Aeolidiella sanguinea* as being of national significance in terms of rarity.

The likelihood is that the first three species are generally under-recorded by UK surveys. The grey muddy colonies of *Anguinella* are quite large but easily overlooked. *Farella repens* is a miniscule but distinctive species requiring careful microscopic examination. Although the 'brain-like' mound colonies of *Suberites massa* that abound within the Port of Poole are very distinctive (Figure 6), this species can also grow as encrusting patches that bear a superficial resemblance to *Hymeniacidon perleve*, a common shore species. In view of the occurrence of all three species in dock locations, their status should be viewed as 'cryptogenic', i.e. it is not clear as to whether they are native or non-native.
As reported by Dyrynda (1991), it is likely that the single sea slug collected in the outer South Deep during the baseline surveys and identified as *Aeolidiella sanginea* (Dyrynda, 1985) is in fact *Aeolidiella alderi*, less uncommon but still viewed as rare in UK waters.

Natural habitat loss

Sub-tidal losses are most evident with the port area, along the sides of the channel leading into Holes Bay, and within the outermost section of the Wareham Channel, and have involved sedimentary seabed areas (mud, sand and shingle).

With reference to gains, harbour walls, breakwaters, pilings and other fixed structures serve as artificial reefs colonized heavily by a diversity of seaweeds and invertebrates. Pontoon floats located within the harbour's many small vessel marinas also support rich populations of seaweeds, invertebrates and fish, the composition being significantly different to those of fixed structures.

The benefits of artificial reefs are well-known from the studies elsewhere, including work undertaken by Southampton University on a constructed reef in Poole Bay (Mallinson *et al*., 1999 and others). However, one potential disbenefit of docks and marinas as artificial reefs is their obvious role as relay points and incubators for non-native species (see below).

Habitat degradation

Navigational dredging

Navigational dredging represents a radical form of physical disturbance regarding benthic habitats and the benthos in that both are removed totally. Survey data from the harbour suggests that recovery may be slow and the end-point habitats and communities may well be quite different to the natural ones prior to dredging. Dredging is, however, confined to certain channels, leaving others unaffected.

Dredging for shellfish ground clearance and stock harvesting

Oyster dredging represents a much less radical form of disturbance than the aforementioned, although the impact of intensive shellfish dredging can be significant. Intensive dredging favours robust species such as the Slipper Limpet at the expense of relatively sensitive forms such as the Peacock Worm. Intensive dredging is confined to limited areas operated by leaseholders leaving most of the channel system relatively undisturbed.

Chemical disturbances

The poor flushing characteristics of Poole Harbour in general and Holes Bay in particular are well recognized, as is the associated vulnerability regarding pollution (Falconer, 1986; Langston *et al*., 2003).

Eutrophicating pollutants

Plant nutrients arising from fertilizers, detergents, sewage, silage and other animal wastes have caused major problems in many estuaries and lagoons around the world. Eutrophication can have a deleterious effect on biodiversity. Concerns about excessive growth of the Sea Lettuce *Ulva lactuca* were already being expressed during the 1960s and 1970s, particularly in the context of Holes Bay (Savage, 1971; Portsmouth Polytechnic, 1981; Langston *et al*., 2003). The more recent, major build-up of *Ulva rigida* across the main harbour basin would suggest further increases in enrichment have occurred. As well as suppressing biodiversity, there is the risk of crises comparable with those seen in Italian lagoons, involving mass mortalities of invertebrates smothered by live or decaying seaweeds or asphyxiated by low dissolved oxygen levels associated with high rates of decay of organic matter. Mass mortalities of mussels in the harbour during the mid-1990s may have been linked to this, although thermal stress is considered a more likely causative factor (Dyrynda and Brown, 1998).

Exceptionally high frequencies of shell disease reported for the Brown Shrimp *Crangon crangon* in Poole Harbour channels may represent another consequence of eutrophication (Dyrynda, 1998).

Toxic metals and organic substances

Chemical pollution has been a recognized problem within Holes Bay since the 1970s. A succession of studies has identified elevated levels of cadmium, mercury and other toxic metals within both sediments and organisms (Boyden, 1975; Langston, 1982; Langston *et al*., 1987, 2003). During the 1980s, exceptionally high concentrations of tributyl tin (then much used in antifouling paints) were recorded in Holes Bay, and abnormal gross shell thickening in farmed stock of the Pacific Oyster *Crassostrea gigas*, a bioindication of TBT pollution, proved problematical in the south side of the main harbour basin. The latter was alleviated by the 1987 partial ban on the use of TBT antifouling paints on vessel hulls (Dyrynda, 1992). It is known that TBT affects a much wider range of organisms than just oysters, although most are of no economic significance. It is worth noting that the baseline surveys of the 1980s were undertaken at a time when TBT levels in the harbour were very high. The effects of this on the baseline species inventory remain unknown.

Unsustainable exploitation of living natural resources

Natural stocks of harvestable marine life within the confines of Poole Harbour are limited in scale. Flat Oyster populations, now at a fraction of their historical levels, were undoubtedly overfished in the past, although the tradition during the 1800s was to deposit a proportion of stock harvested from open coastal waters within the channels of the harbour (Philpots, 1890). Although harvesting is now regulated, disease outbreaks, the presence of the North American Slipper Limpet and overfishing have all hampered the natural recovery of this species.

Non-native species introductions

The baseline surveys of the 1980s revealed a huge presence of non-native species in the tidal channels of the harbour, and subsequent monitoring shows that new species continue to arrive on a regular basis. These non-native species are causing major changes to the structure of natural communities within the low water channels, with at least partial displacement of 'native' biota. The North American Slipper Limpet *Crepidula fornicata* is the dominant epibenthic species in the harbour channels. It clearly out-competes the native Flat Oyster *Ostrea edulis* and now occupies large areas of the seabed that were probably favoured by the European Flat Oyster in previous times.

The impacts of some of the other arrivals are less easy to assess, and some argue that biodiversity is being augmented rather than depressed. For example, *Sargassum muticum* provides a substratum for a multitude of epiphytic algae and invertebrates.

At least six new arrivals have been documented for the harbour over the past 6 years or so including several during the 2003 dredging survey. Most invaders go unnoticed until a specialist survey discovers them, although the large brown seaweed known as Wakame *Undaria pinnitifida*, now in early stages of consolidation, may become almost as conspicuous as *Sargassum muticum*.

In view of the long maritime history of the port, it is likely that many species were introduced before records began. The old sailing ships were often very heavily fouled, and were ideal carriers for non-native biota. For several centuries Poole conducted intensive trade with Newfoundland and New England. Poole Oyster Company was importing live oysters from North America and southern Europe during the late 1800s (Philpots, 1890) and it is certain that other species would have been introduced with them.

The presence of a large number of non-native species adds a tier of instability and complexity to the system as invaders wax and wane over different time-scales, presenting real challenges for the analysis of stability and change in the harbour environment.

Climate change

Impacts of rapidly rising sea levels and temperatures may be substantial within Poole Harbour over the coming decades and centuries. Rising sea levels may ultimately cause enlargement of the harbour, perhaps resulting in ecologically significant changes to the hydraulic regime. Recent hot summers such as that of 1995 may have provided an indication of some ecological impacts likely to be caused by sustained warming. Exceptional mortalities of farmed mussels and unusual blooms of nuisance algae were documented in 1995 (Dyrynda and Brown, 1998). Higher temperatures are likely to be accompanied by distributional shifts in the north-east Atlantic as species adapted to both colder and warmer conditions shift northwards.

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