The Ecology of Poole Harbour
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# 2. Geomorphology of Poole Harbour

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The geomorphology and sedimentation of Poole Harbour are poorly described although there are many localized studies within the harbour. Water level changes, both within the archaeological time-scale and at the present, may be a result not only of eustatic and regional isostatic changes but also of the effects of changes in tidal prism. Variations in marsh, intertidal areas and beaches have had important effects on the ecology of the harbour. Further investigation is needed of the landforms underlying both Sandbanks and the Studland dunes, as well as the responses of the intertidal areas and shore to changes in water levels.

## Introduction

Poole Harbour is one of several estuaries in south-central England which are enclosed by spits and bars at their mouth and resulted from the drowning of valleys flowing into the English Channel. At High Water Spring Tides, its area is about 3600 ha, 1000 ha less than 6000 years ago. It has a single entrance and a long channel seawards between extensive sand shoals. There are three main channel networks. South Deep drains the southern lowland heaths, and the Wych Channel drains the Corfe River catchment. The northern harbour forms the estuary of the Rivers Frome and Piddle (with a combined catchment of over 770 $km^2$) and two smaller embayments with very restricted mouths, Lytchett Bay (the Sherford River estuary) and Holes Bay (draining the heathlands around Creekmoor). Much of the natural shoreline is marked by a low bluff (commonly less than 5 m in height) and eroding cliffs, but the northern shoreline is mainly artificial with walls, embankments, marinas and wharves. Tidal range is small (1.8 m at spring tides, 0.6 m at neaps at Poole Quay) and a double high water often holds water levels above mean tide level for 16 out of 24 hours. Tidal range increases upstream. Saltmarsh is confined to a relatively narrow fringe contained within a vertical elevation from around +0.05 m to +1.3 m Ordnance Datum (OD). The intertidal mudflats are not available for wading birds to feed on benthic invertebrates for extensive periods. The harbour has relatively poor flushing characteristics.

The geomorphology of Poole Harbour is poorly described. Most investigations focus on the accumulation and release of sediment associated with the spread and dieback of *Spartina anglica* (Bird and Ranwell, 1964; Gray, 1985; Gray *et al*., 1995; Raybould, 1997), sedimentation and dredging in the main navigable channels (Green, 1940; Green *et al*., 1952; Halcrow Maritime, 1999) and the development of the harbour mouth beaches and dunes (Diver, 1933; Robinson, 1955; Carr, 1971; May, 2003). Investigations of the Holocene sediments typically focus on the vegetational history (Haskins, 1978) or interpretations of sea level change (Nicholls, 1986; Edwards, 2001, Long *et al*., 1999).

## The morphology of the harbour and its entrance

The morphology of the harbour is dominated by intertidal banks and slopes and sub-tidal channels mostly in loose sediments resting on the rarely exposed underlying Poole Formation (Fahy *et al*., 1993). The channel depth at the harbour mouth is about -15 m LAT (about -16.4 m OD). However, the depth of bedrock in the Swash Channel off Shell Bay is about -10.6 m OD (BP Exploration, 1991). East of the Hook Sands, a channel about 1 km wide attains depths in bedrock of about -14 m OD (BP Exploration, 1991).

The landward edge of much of the harbour is marked by:

- a low bluff typically less than 5 m in height or
- actively or partly degraded cliffs up to 10 m in height or
- artificial structures (May, 1969).

To seaward, there are extensive saltmarshes and mudflats or small sand and shingle beaches. The highest level of active wave erosion of cliffs varies in height (between about -0.6 to -1.1 m OD). However, at Shipstal, most cliff foot retreat occurs during periods of high wave-runup to above High Water Springs. Shore platforms cut into bedrock typically have a narrow upper slope of about 1 in 8 and then a wider slope seawards at angles of between 1:80 and 1:120. Beneath the saltmarsh, there is occasionally a step about 0.5–0.6 m high between -0.6 m OD and -1.1 m OD (Edwards, 2001). The saltmarsh surface typically falls in the southern harbour from about +1.3 m OD to +0.05 m OD, where it is truncated by an eroding cliff about 0.2– 0.3 m in height.

## Tides, waves and sea level rise in Poole Harbour

The geomorphology of the harbour results from the combined effects of:

- marine and sub-aerial processes on both intertidal zone and shoreline
- the channel hydrodynamics
- anthropogenic modifications of the shoreline and channels
- catchment hydrology affecting both the freshwater and sediment inputs
- the spread and decline of the saltmarshes.

Sea level rise, tides and waves affect the estuary on different time-scales, the effects of waves varying with the tidal cycle and water levels (Table 1). Low-angle intertidal slopes within the harbour mean that these combined effects may be detectable over the time-scale of the *Spartina* era.

**Table 1 Estimates of sea level altitude and change**

**(a) Changes up to late nineteenth century**

| Location | Dates | Altitude (m OD) | Source | Period and direction of change | Years | Mean annual change (mm $year^{-1}$) derived from sources |
|---|---|---|---|---|---|---|
| Hamworthy | 7340 +/ 110 BP | -12.8 | Godwin *et al.* (1958) | Rising 7340–6000 BP | 1340 | +9.6 |
| Poole Harbour | 6000 BP | Present level | Bird and Ranwell (1964) | Stable with slight falls | | |
| Arne and Newton Bay | | | Edwards (2001) | Rising 4700–2400 BP | 2300 | +0.26–0.7 |
| Arne and Newton Bay | | | Edwards (2001) | Falling/stable 2400–1200 BP | 1200 | |
| Brownsea | End third century AD | - 2.7 | Jarvis (1992) | Rising 1600 to present | 1600 | +1.7 |
| Arne and Newton Bay | | | Edwards (2001) | Rising then stable 1200–900 BP | 300 | |
| Arne and Newton Bay | | | Edwards (2001) | Rising 400–200 BP | 200 | |
| Arne and Newton Bay | | | Edwards (2001) | Net rise 4700–200 | 4500 | +0.53 |

**(b) Post nineteenth century changes**

| Location | Dates | Altitude (m OD) | Source | Period and direction of change | Years | Mean annual change (mm $year^{-1}$) derived from sources |
|---|---|---|---|---|---|---|
| Keysworth | 1912–1966 | | Hubbard and Stebbing (1968) | Rising | 54 | +1.85 |
| Poole | Current | | Pethick (1993) | Rising | | +4.0 |

Although close to present levels for the last 6000 years, sea level has been lower during that period (Table 1a), rising and falling within a vertical range of about 3 m (Edwards, 2001; Long *et al*., 1999). During this period, the rate of change in sea level was significantly lower than in either the preceding period of very rapid rise or in the present much shorter period of accelerated sea level rise. The altitude of the marshes and shoreline erosion also depend on variations in wave heights and tidal range. Hubbard and Stebbing's (1968) estimate suggests that sea level would have risen by 170 mm between 1912 and 2004. However, recent estimates imply that sea level rise since the mid-1960s has been faster. Combining these two estimates indicates a net sea level rise since the arrival of *Spartina* of about 0.28 m. Hubbard and Stebbing (1968) give High Water Spring Tides at +0.79 m OD, but Halcrow Maritime (1999) has Mean High Water Springs at +0.9 m OD, a difference equivalent to an annual rise of 3.5 mm between 1966 and 1997, i.e. consistent with Pethick's (1993) value. Given the low angle slopes of the intertidal areas (often flatter than 1:100), such a rise of water levels has implications for marsh edge beaches and cliff retreat, as well as the plant communities around the estuary.

The tidal range at Poole North Haven is 1.7 m (Halcrow Maritime, 1999). Green (1940) showed that the tidal peak not only lagged upstream, but also the tidal curve steepened upstream during the flood tide. Ranwell *et al.* (1964) estimated the tidal range at Keysworth as 2.9 m. Edwards (2001) in contrast has tidal ranges of 1.2 m and 1.6 m at Arne and Newton Bay, respectively. The tidal prism, i.e. the volume of water exchanged on each tidal cycle, is affected by the shape of the estuary. If land claim or accretion occur, the intertidal volume is reduced and estuaries adjust by changing the shape of the estuary mouth. Poole, however, has an artificially narrow mouth and so reduced tidal prism is likely to cause water levels to rise and the sub-tidal channels to deepen (Table 2). Varying water levels during the past century may result from these local conditions rather than sea level rise alone. Tidal currents attain 2.0 m $s^{-1}$ in the entrance channel, but are generally slower in the main channel: 0.5 m $s^{-1}$ (Halcrow Maritime, 1999). Ebb-dominated in terms of the currents, the estuary as a whole is wave-dominated in terms of the overall energy distributions, but there is a contrast between the ebb-domination of the lower harbour and the flood-dominated upper estuary (Green, 1940).

Wind direction and strength and fetch affect wave formation. Refracted English Channel waves affect the harbour mouth and open-coast beaches, but do not penetrate the majority of the harbour. Winds of about 15 knots will generate waves with significant wave height $H_s$ 0.38 m over a fetch of 5 km (the distance from Parkstone Bay to Shipstal Point) and similar winds blowing from WNW would generate waves with $H_s$ 0.40 m at Shore Road.

## Geomorphological history of the harbour

The harbour is cut into the Bracklesham Group, mostly the Poole Formation, an "alternating sequence of fine- to very coarse-grained, locally pebbly, cross-bedded sands, and pale grey to dark brown, carbonaceous and lignitic, commonly laminated

**Table 2 Key hydrodynamic and morphological changes during the *Spartina* era**

| | **Saltmarsh area** | **Tidal prism** | **Sub-tidal channel depth** | **Tides and currents** | **South Deep** |
|---|---|---|---|---|---|
| c.1880–c.1925 | Increase area = 775 ha by 1925 | Decrease c. 20% | Increase | Intertidal elevation increase | 50% deeper |
| 1925–present | Dieback area = 415 ha in 1980 | Increase c. 11% | Decrease | Increased ebb currents at harbour mouth | 20% shallower |

Source: Based on Gray *et al.* (1995).

clays" (Bristow *et al.,* 1991, p. 33). The earliest preserved geomorphological landscape comprises valleys and terraces associated with the Solent River (Everard, 1954). River Terrace Deposits, typified by gravel and sand deposits up to 3 m thick, occur at altitudes up to +50 m OD.

As sea levels fell, the rivers cut channels to at least -13 m OD, forming a landscape of rivers meandering between low hills and ridges separating the northern estuary from the south. Wright (1982) suggested that a southern re-orientation of the drainage in Poole Bay began in the early Devensian. Velegrakis (1994) argued that an 'English Channel' river flowed directly southwards. Tyhurst and Hinton (2004) suggested that Poole Bay was deeper than Christchurch Bay for much of the late Holocene, arguing that, as the bays flooded and the coastal configuration changed, tidal range would also alter. The nature and rate of coastal changes would thus differ from today.

As Holocene sea level rose, the valleys flooded, establishing the present pattern of deep channels. Sea level probably attained present levels about 6000 years ago, but archaeological investigations suggest lower sea levels both during the Iron Age (Wilkes, pers. comm.) and in the late third century AD (Jarvis, 1992). With mean tide level (MTL) about -2.7 m OD, but assuming that tidal range has not changed, erosional retreat processes would occur along the cliffed coast at about -1.8 m OD. This appears consistent with the step under Arne (Edwards, 2001). MTL does not always represent the shoreline or the level at which erosion processes will be concentrated, i.e. the underlying bedrock surface may slope upwards as it does today. Moreover, assuming that wind strengths and storm events were similar to today, most direct erosion of the shore would occur below MTL. The presence of sand layers in corings at Arne and Newton Bay (Long *et al*., 1999; Edwards 2001) does not necessarily imply an erosional phase, since within the harbour such deposition of sandy deposits also depends upon transport patterns, the supply from existing cliffs and the presence of marsh surfaces on which deposition can occur. Phases of greater wave energy or shifts in wind direction (and so wave climate) may also produce areas of deposition on existing marshes.

For the past six millenia, channels, islands and intertidal ridges and flats have characterized the harbour. Although the harbour mouth is well established, the point at which the harbour flooded during the period of rapid sea level rise is not certain. The Godwin *et al*. (1958) dating for marine sediments overlain by freshwater peat at Hamworthy would put sea level about 7500 years BP about -12.5 m OD. However, with the bedrock altitude in the Swash Channel at -10.6 m OD, the sea could not enter the harbour by this route. The deeper bedrock channel east of the Hook Sands (and coincidentally opposite the narrow neck of Sandbanks) lies at about -14 m OD. If this channel extends landwards (for which currently there is no direct evidence), this would provide evidence of a separate entrance to the northern harbour between Sandbanks and Flag Head. This needs investigation.

Finally the arrival of *Spartina anglica*, large-scale reclamation around Poole and the regular maintenance and capital dredging of the main channels have altered the detailed shape of the estuary. Much of the northern shore has been reclaimed, the overall area of the estuary has reduced and the tidal prism has been restricted.

## Recent sedimentation and change within the harbour

There was little change in patterns of channels, mudflats and fringing marshes until the end of the nineteenth century (Table 3). *Spartina* growth captured about 7 million $m^3$ of sediment by 1925, but as saltmarshes died back, at least 4 million $m^3$ was released (Gray *et al*., 1995).

Most marsh sediments are fluvial in origin. The embayments are typically areas of accretion, often reclaimed and so trapping suspended sediments. Cores and boreholes

**Table 3 Recent trends in harbour hydrodynamics**

- Under 3 million $m^3$ fine sediment still retained in saltmarsh but reducing
- Channel width at harbour mouth fixed and channel scoured and dredged
- Tidal prism not yet returned to pre-*Spartina* level
- Tidal prism reduced by land claim
- Sub-tidal channels deeper than pre-*Spartina* but shallowing in upper estuary
- Approximately 0.26 m water level rise since late nineteenth century

vary from 3.0 m to 21.3 m deep before the underlying Poole Formation strata are reached (Bristow *et al*., 1991). Most contain layers of peat. The deepest at Ferry Road (SZ 008 902) identified bedrock at 21.3 m *below the surface.* 'Oyster' shells at depths of up to 7.3 m *below the surface* were underlain by shelly soft clay changing downwards to silty sand. At SZ 00679007, a 1.0 m layer of silt containing peat occurred at 8.3 m and the Poole Formation at 11.3 m *below the surface.*

Sedimentation was rapid under the influence of *Spartina*. At Keysworth seaward of the reedswamp, Hubbard and Stebbing (1968) reported marsh sediments 1.98 m thick. The muddy upper marsh lay between +0.77 m OD and -0.84 m OD, with over 0.95 m sand above 0.1 m peat resting on gravels and Bagshot Beds at –1.21 m OD. In contrast, the lower central marsh sediments were over 6.25 m thick. Following *Spartina* colonization in 1912, the mean annual accretion rate was 32 mm. However, annual rates were greater (e.g. 80 mm in 1963; up to 150 mm in 1966). Total post-*Spartina* accretion was estimated at over 180 cm at Keysworth, 70 cm in Arne Bay and 35 cm in Brands Bay (Bird and Ranwell, 1964; Ranwell, 1964; Hubbard and Stebbing, 1968). There are few measures of sediment input from the rivers. Hubbard and Stebbing (1968) give a sample estimate of suspended matter at Wareham Quay of 36,700 kg per day but much of this may be organic. May (1969) noted that the annual provision of sediment from the rivers was limited. Changed agricultural practices in the catchment may have altered the patterns of soil erosion, particularly in the autumn.

Maximum salinity coincides with minimum sediment concentration at the junction of the Main and Middle Channels (Green, 1940). The channels, except for Main Channel, only shifted position slightly during the nineteenth and early twentieth centuries. Main Channel had phases of movement towards the east and north-east between which it moved little but became shallower. The sediments of the estuary are generally fine (Green *et al*., 1952), but relatively coarse in the area between Brownsea and Salterns. Suspended sediment distributions have been modelled by Falconer (1984) and Falconer and Chen (1991) using finite differences solutions to predict time varying water elevations, velocity, bed shear stresses and suspended and bed load sediment flux concentrations. For Poole harbour as a whole (Pethick and Forster, 1994), the highest values occur in the entrance channel, in the main channel east of Brownsea and in the channels between the islands.

## The beaches and cliffs within the harbour

Cliff erosion provides the many small beaches with gravel and sand. Gravels often form layers on the upper part of the intertidal flats. Some gravel is rafted onshore attached to wracks. Beaches inside the harbour typically show a cliff: cliff-foot beach: spit pattern, often with a post-*Spartina* chenier on the marsh edge. There are also some larger sandy spreads especially between the islands. Before *Spartina* colonized, the islands and headlands, such as Baiter, commonly had a spit extending eastwards along the southern shore and recurving northwards at the eastern end of the island. On the northern side of the islands and peninsulas, fringing beaches with small ness-like areas of sand and gravel beach ridges (e.g. Seymours on Brownsea Island) are more common. After *Spartina* spread, marsh-edge beaches become more common.

Cliff erosion affects the northern shore and the islands. The estimated annual retreat rate of the cliffs during the nineteenth and early twentieth centuries was 0.4 m (May, 1969). The cliffs on Green Island have probably retreated about 170 m since the Iron Age (i.e. 0.06 m year$^{-1}$) . For much of the twentieth century, *Spartina* protected existing cliffs, retreat rates fell to about 0.1 m year$^{-1}$ and many former cliffs degraded to become well-vegetated slopes: e.g. at Portland Hill, Brownsea Island, retreat of the shoreline averaged 0.1 m year$^{-1}$ pre-*Spartina*, fell to 0.02 m year$^{-1}$ with *Spartina* protection and then increased to 0.85 m year$^{-1}$ when saltmarsh eroded. The shelter afforded by the islands has decreased with sea level rise and cliff erosion. Parts of the cliffs at Goathorn are retreating at present and earlier features are being reworked.

The cliffs and beaches at Shipstal, where a spit is first recorded in 1785, demonstrate the complexity of interaction between changes in wave energy distributions, cliff retreat and sediment supply and transport, the role of saltmarsh and changes in water levels. Nineteenth century beach development was limited (May, 1976), but the spread of *Spartina* in Arne and Middlebere bays altered local wave patterns and provided a base for extended beaches. A new beach formed southwards and the northern beach extended into Arne Bay into deeper water, and on to looser sediments. May (1981) predicted, based on an investigation of the sediment budget, that the historical pattern would change because of three linked factors: a reduced supply of sediment from the south, increased frequencies of north-easterly winds, and a decline of the proximal area of the beach and an increase in overwash. Since the 1980s, this pattern has dominated, but erosion of the proximal beach has increased, so that the older (eighteenth and nineteenth century) ridges eroded by about 20 m since 1970.

## The beaches and mouth of the harbour

The beaches and dunes at the mouth of Poole Harbour have been the focus of investigations for many years. In particular, the development of the dunes on the South Haven peninsula has been well documented (see May, 2003, for summary) and so will not be discussed further. Investigations by Halcrow Maritime (1999, 2004) analysed contemporary processes in detail, largely corroborating earlier studies.

The main source of sand appears to be the seabed: extensive sand banks occur throughout the cartographic record. It is unclear why there was a sudden onset of dune building in the seventeenth century (Diver, 1933), and there is no explanation of the wide intertidal area forming their base. The early history of the dunes is, therefore, far from clear, although it is certain that the dunes at Studland have an earlier origin than Diver or later writers suggested (May, 2003). Both the sub-dune surface and the sedimentation processes on South Haven need further investigation.

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