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Changing coastlines in NE England: a legacy of colliery spoil tipping and the effects of its cessation

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Abstract: Historical tipping of vast quantities of colliery spoil at various foreshore locations in NE England has changed the morphology and sedimentology of large areas of the shoreline and nearshore sea bed, and has impacted adversely upon the ecology and amenity use of the area. Tipping started early in the 20th Century, well before statutory controls to regulate impacts of activities on the marine environment came into force in the UK in 1974, and ended with the closure of the last colliery in 2005. The spoil tipping acted as a form of artificial sediment recharge to the foreshore, akin to conventional beach recharge schemes that use sand or shingle to replenish foreshores for coastal defence and amenity purposes, but creating a legacy of contaminated beaches and prograding (advancing) shores. Since closure of the collieries, however, the foreshores have received no artificial supply of material, and the shoreline in all former tipping areas has since been in retreat due to natural erosion. This has caused problems where assets are present at the rear of the spoil beaches, requiring coastal defence structures for their protection. As well as collating and analysing historical maps, records, literature and data relating to colliery spoil tipping, the coastal changes that have occurred since its cessation have been assessed by reference to more recent maps, literature, aerial photographs and new and up-to-date beach profile transect survey data from contemporary coastal monitoring programmes. It is envisaged that where sea cliffs are protected by colliery spoil beaches, and hence currently are dormant, they could become re-activated by erosion and start to retreat at short term rates of several metres per year and longer-term rates of up to 0.3 m/year in the foreseeable future.

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Coal mining was arguably once the single most important industry in NE England as it helped to fuel the steam-powered technological advances that occurred throughout Great Britain's Industrial Age. As resources became exhausted from the earliest pits, which were established to exploit shallow seams across the Durham and Northumberland coalfields, and as technological advances through the 19th Century enabled deeper mining methods, many further seams were opened-up. Some of the newer pits within the counties of Durham and Northumberland were located close to the coast in order to exploit under-sea reserves, and these 'coastal pits' commenced production around the beginning of the 20th Century. The volume of coal extracted rose significantly with increased mechanization after the Second World War (Temple 1994*a*, *b*; Tuck 1993, 1995).

Colliery spoil from many of the coastal pits in the counties of Durham and Northumberland was deposited on the adjacent foreshores (Fig. 1). This was done by tipping, either directly over the cliff top or from aerial 'flights' (conveyors that extended across the foreshore to deposit spoil just beyond the low water mark). At the peak of production, between the mid-1960s and early 1980s, tens of millions of tonnes of colliery spoil in total were tipped onto foreshores (Hydraulics Research Station 1970; Durham Heritage Coast 2002). This had two significant effects on coastlines at the dump sites. First, it 'contaminated' the natural beaches, causing adverse ecological and amenity effects. Secondly, it acted as a form of 'recharge' of foreshore material, resulting in significant progradation of the shore and in places pushing the line of mean high water seawards by more than 100 m (Hyslop *et al.* 1997).

Prior to tipping, the alongshore transport of marine sediments was inferred to be generally confined within small bays separated by rock headlands (Steers 1964). The growth of spoil beaches beyond the extent of headlands improved coastal linkages and enabled alongshore sediment transport over greater distances (Nunny 1978). In consequence, colliery spoil also began to accumulate in bays that were not directly affected by tipping, but were located further down-drift (Posford Duvivier Environment 1993).

In Lynemouth Bay, Northumberland, where direct tipping did take place, the accumulation of colliery spoil on the foreshore was so extensive that a coal-fired power station was built on the prograding shore, opening in 1972. Along the foreshore tipping sites in County Durham, the backing cliffs were separated from marine processes by the increasing width of spoil beach and so became stabilized and well vegetated.

Since closure of the collieries, the foreshores have received no artificial supply of material. As a consequence, the spoil beaches have started to erode landwards (Cooper *et al.* 2009). In Lynemouth Bay, colliery spoil tipping was temporarily stopped in 1994 when the nearby colliery was closed, although it re-opened the following year and continued in production for a further decade. Upon the temporary cessation of tipping in 1994, the spoil beach rapidly eroded

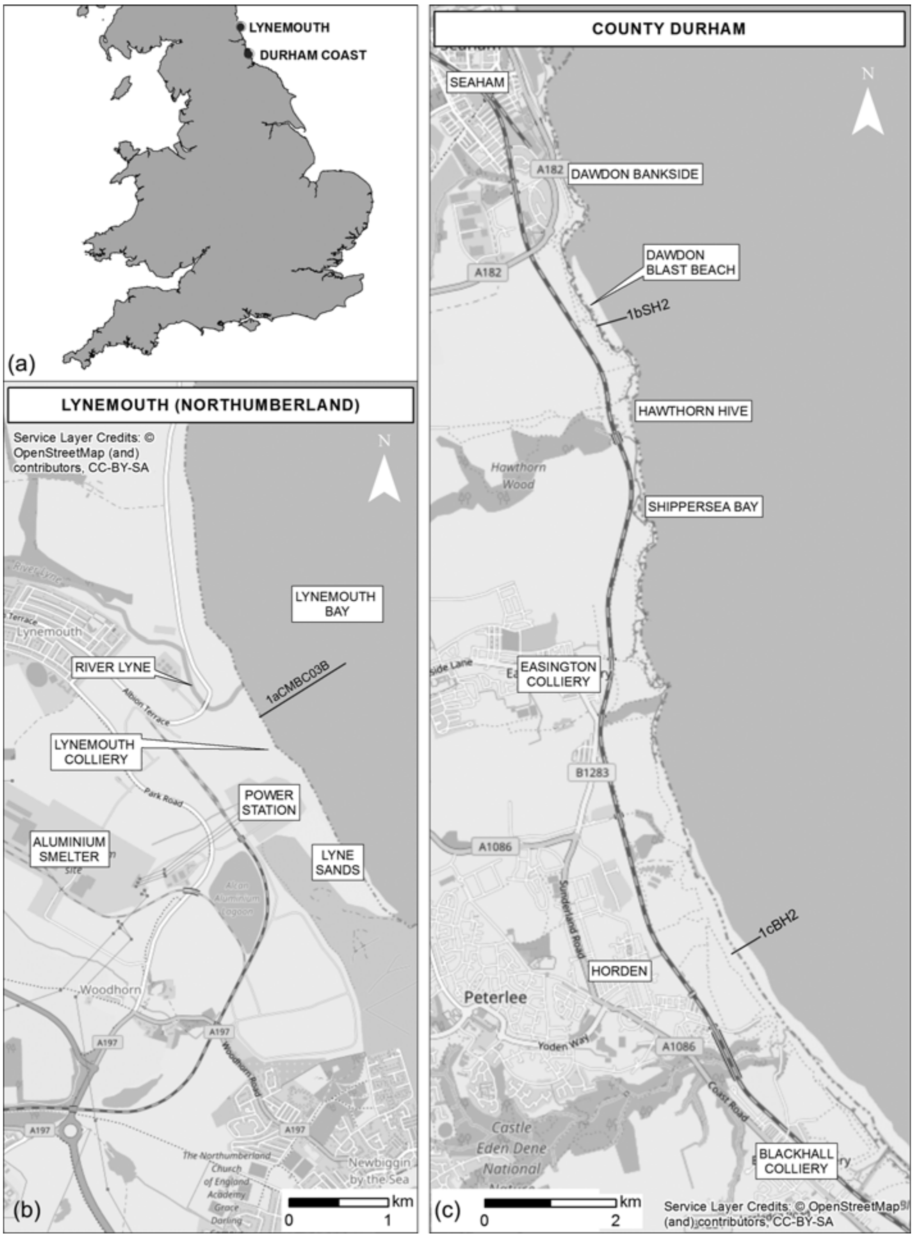

Fig. 1. Location maps. (**a**) Location of Lynemouth and Durham coast sites in NE England. (**b**) Lynemouth, Northumberland, showing the positions of Lynemouth Colliery, Lyne Sands, the Lynemouth Power Station and transect 1aCMBC03b. (**c**) Spoil tipping sites on the County Durham coast between Seaham and Blackhall Colliery and the locations of transects 1bSH2 and 1cBH2.

landwards and the power station at Lynemouth Bay was flooded by overtopping sea water during storms in the winter of 1994 – 1995 (Posford Duvivier 2000). In response to this, a rock revetment was constructed around the power station in 1995, and this was extended in 2005 – 2006 in response to further erosion to the north of the site, after the colliery finally closed in 2005 and spoil tipping ceased entirely. Similarly, since the final closure of the Durham Coalfield collieries in the 1990s, the foreshores there have received no artificial recharge of material. As a consequence, the spoil beaches have started to erode landwards, in places initially by up to 20 m each year, but reducing around 2 – 5 years after the cessation of tipping to 0.5 – 2.0 m/year as erosion encroached into older, more consolidated spoil (Posford Duvivier 1993).

The aims of this paper are: (1) to use an established analytical technique called Historical Trends Analysis (HTA; see Pye & van der Waal 2000), involving the collation and analysis of historical maps, records, literature and data to summarize the effects that colliery spoil tipping has had in changing the coastline at various foreshore sites in NE England; and (2) to summarize the coastal changes that have occurred since cessation of spoil tipping following closure of the coastal pits by reference to more recent maps, literature, aerial photographs and data from contemporary coastal monitoring programmes. Reference is also made to a major restoration programme called *Turning the Tide* that was delivered between 1997 and 2002 to enhance the conservation, recreation and access value of the Durham beaches.

Historical trends analysis (HTA)

The HTA presented in this paper has involved the collation and review of published papers and ‘grey’ literature pertaining to previous research into the effects of colliery spoil tipping, the compilation of tipping volumes from available records, and the analysis of historical maps to determine past changes in the shoreline.

Colliery tipping in NE England

Eagle *et al.* (1979) undertook a comprehensive field assessment of the effects of dumping solid wastes off the

NE coast of England. In most cases, the dumping of such wastes started well before statutory controls to protect the marine environment came into force in the UK, in June 1974, with the enactment of the Dumping at Sea (DAS) Act 1974. Since then, disposal of these wastes has been regulated under licence by the appropriate regulatory body at the time (previously the Ministry of Agriculture, Fisheries and Food (MAFF), currently the Marine Management Organisation).

Eagle *et al.* (1979) presented the results of five surveys carried out by Fisheries Research off the NE coast between March 1974 and April 1977, as part of MAFF's (then) responsibilities under the DAS Act 1974 to protect fisheries and the marine environment. The specific aims of these surveys were: (1) to characterize the area in physical, chemical and biological terms so as to provide a benchmark to compare with the results of subsequent surveys; (2) to identify the sites of deposition and subsequent dispersal pathways of the dumped waste; and (3) to identify the effects of dumping on the physical and chemical characteristics of the naturally occurring beach and seabed sediments and to define the resulting biological effects.

At the time of Eagle *et al.*'s (1979) report, large quantities of colliery waste, known colloquially as 'minestone', needed to be disposed of locally. Minestone originates from the coal washery and comprises mostly angular grey shale with some sandstone. The waste was reported to comprise predominantly gravel-sized clasts, *c.* 90% of which were coarser than 2 mm with a maximum diameter of about 300 mm, with very little material finer than 100 µm in the initial deposit (Eagle *et al.* 1979).

Anecdotal evidence suggests that, immediately after tipping, the clasts would rapidly break down into smaller constituent grain sizes and that some particles, especially those of the finest grain sizes, would be washed-away from the dump site. However, due to the volumes of tipping involved, the supply of material exceeded the rate of removal and hence the shorelines prograded (advanced seaward). Colliery spoil is highly sensitive to moisture and the spoil remaining on the beaches changed over time through geochemical processes into a clay-like substance interspersed with sand, rock and other debris (e.g. rubber tubing, etc.). Its more consolidated nature made it more resistant to erosion than its constituent grains and, whilst tipping remained active, the shorelines continued to prograde.

The quantities of colliery spoil tipped onto the foreshore or taken to offshore spoil grounds in 1976 and 1977 are shown in Table 1 from Eagle *et al.* (1979). Note that formal reporting of disposal quantities only started in 1976, after enactment of the DAS Act in 1974.

Table 1. *Quantity of colliery spoil disposed off the NE coast of England in 1976 and 1977*

Dumping site	Quantity dumped in 1976 (tonnes × 10^6)	Quantity dumped in 1977 (tonnes × 10^6)
Lynemouth (foreshore)	1.18	1.20
Blyth (spoil ground)	0.21	0.30
Souter Point (spoil ground)	0.57	0.85
Wear (spoil ground)	0.63	0.85
County Durham (foreshore)	1.21	2.50

Data from Eagle *et al.* (1979).

In order to investigate the fate of the spoil, and the environmental effects of the foreshore and offshore dumping activities, Eagle *et al.* (1979) analysed a large number of sediment grab samples covering an extensive area of the sea bed off the coast of NE England, collected between March 1974 and April 1977. At each sampling station, the upper 10 mm of sediment was analysed for particle size distribution, carbon content and the presence of heavy metals. Eagle *et al.* (1979) found that: (1) the carbon content of the minestone waste was *c.* 20%, with coal being present as inclusions in the shale fragments of the gravel-sized faction and as some free coal observed among the finer particles; (2) the coal particles have a density of *c.* 1300 kg/m^3, compared with the shale density of 2650 kg/m^3; and (3) the colliery waste contained quite high concentrations of trace metals as a result of the inclusion of coal particles. In addition, a number of observations were made by Eagle *et al.* (1979) from Direct Reading Current Meters (DRCMs) and Moored Reading Current Meters (MRCM), to supplement information on tidal currents available from tidal diamonds on Admiralty charts. Sea bed drifters were also released from two stations as part of previous research: offshore from the River Tyne by MAFF in 1975 and offshore from the River Wear in 1971 (Watson & Watson 1971). From the current meter and sea bed drifter information, it was apparent to Eagle *et al.* (1979) that tidal streams are aligned parallel to the coast during the periods of strongest flow. Inshore, the tidal ellipse was noted to be very narrow, with little flow normal to the main axis, whilst offshore the ellipse had a greater east–west component.

The following factors were identified by Eagle *et al.* (1979) as influencing the dispersal of the solid wastes dumped offshore at the spoil grounds.

(1) The solid wastes dumped offshore were released from large vessels via bottom-opening doors while the vessel was stationary or slowly underway. The bulk of the material fell through the water column to the sea bed as one mass, settling within a few minutes of discharge. Only a small fraction of the waste was dispersed more widely during settling. Consequently, density variations within the water column and tidal currents immediately following dumping did not significantly affect the initial settlement of these wastes.

(2) Over the longer term, considerable fractions of the wastes dumped offshore were dispersed by tidal or wave-induced currents, running parallel to the shore in a predominantly southwards direction. This process was particularly influenced by the fine-grained nature of the ash and the low density of the minestone, both of which contributed to remobilization of the deposited wastes. It was notable that very little transport occurred normal to the shore (offshore to onshore transport of solid wastes dumped at offshore sites).

For solid wastes dumped on the foreshore, the distribution percentages of sand-sized coal coarser than 0.5 mm indicated to Eagle *et al.* (1979) very little transport of material away from the foreshore tipping sites beyond the surf zone (in contrast to the considerable transport of material away from offshore spoil grounds). Coal particles coarser than 0.5 mm were considered to be transported as bedload rather than as near-bed suspended load, accounting for their more restricted distribution.

In addition, Hyslop *et al.* (1997) assessed the ecological effects of colliery waste disposal on littoral communities in the NE of England. A maximum of two species of macro-invertebrates per shore level (low shore, mid shore and high shore levels) were found at sites characterized by soft sediments that were heavily contaminated by colliery waste, compared to typical background values on uncontaminated shores of about eight species. The principal reasons were stated to be the large quantities of solid material; the release of inorganic chemicals such as trace metals; the release of organic substances such as coal-derived hydrocarbons; and the attenuation of light in the water column by waste particles.

Clearly, colliery spoil tipping in Northumberland and Durham has had an effect on both the morphology and the ecology of the foreshores.

Lynemouth Bay, Northumberland

Lynemouth Bay (Fig. 1) received colliery waste initially from nearby Lynemouth Colliery, which commenced production in 1934 and immediately began tipping waste onto the foreshore at two sites, one to the north of the River Lyne and the other to the south along Lyne Sands (Nunny 1978). Waste from the older Ellington Colliery was subsequently added to this and continued until the colliery's closure in 1994. Tipping recommenced, but only at the northern site, when the colliery was re-opened in 1995, and continued until its final closure in 2005. Tipping resulted in significant seaward movement of the beach front and infilling of Lyne Sands and the wider Lynemouth Bay (Posford Duvivier 2001). Since the cessation of tipping, the shoreline has been retreating in parts of Lynemouth Bay, most notably in the vicinity of the power station and Lyne Sands to the south (Cooper *et al.* 2009).

Historical records of colliery spoil tipping

Colliery spoil (minestone) dumped on the beaches at Lynemouth for several decades from 1934 resulted in an artificially advanced beach front. The advanced beach front was maintained by minestone tipping, initially until 1995, but was sensitive to tipping volumes. For example, in 1994, minestone placement was temporarily stopped, and rapid erosion of around 40 m of the beach front occurred subsequently, during storms in the winter of 1994 – 1995 (Posford Duvivier 2001). This led to the sea flooding the Lynemouth power station and prompted the subsequent construction of rock armour revetment scheme in 1995. The revetment was subsequently extended around the adjacent coal-stocking yard of the power station between October 2005 and March 2006, when the requirement to maintain on-site coal stocks increased following the closure, in 2005, of Ellington Colliery, which had provided coal for the power station. Until closure of the colliery, ongoing tipping of waste directly in front of the coal-stocking yard provided some protection, but following the cessation of tipping, the shore began to erode.

Tipping on the Lynemouth shore between 1934 and 1972 was reported by Nunny (1978). Two tipping sites were used, one to the north of the River Lyne in the northern part of Lynemouth Bay (Fig. 2), and the other to the south along Lyne Sands (Fig. 3). Waste was transported initially by an aerial ropeway, rail wagons and conveyor systems, but when coal production and associated waste production intensified, lorries were used to carry minestone to dump sites along the high water mark.

Tipping records are absent between 1973 and 1975, but the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) kept records of the volumes tipped between 1976 and the initial closure of Ellington Colliery in 1994. Posford Duvivier (2000) then reported that tipping recommenced in front of the coal-stocking yard after the colliery re-opened in 1995 and continued until its final closure in 2005. The quantities tipped between these dates were not available from CEFAS, but were available between 1995 and (August) 2001 from Posford Duvivier (2001). Quantities tipped between 2002 and 2005 remain unknown,

Fig. 2. Colliery spoil beach to the north of the River Lyne in Lynemouth Bay, Northumberland.

Fig. 3. Colliery spoil beach at Lyne Sands in Lynemouth Bay, Northumberland.

but are likely to be of a similar (or smaller, declining) order as in the early 2000s.

The CEFAS database identifies both the ‘total volume’ and ‘volume of solids’ deposited at the beach tipping sites, so the latter data are used alongside the Nunny (1978) and Posford Duvivier (2001) data to show the trends over the length of the data record (Fig. 4). At its peak in 1968, over 1.5 million tonnes were deposited, with around 1 million tonnes per annum each year from 1965 to 1983. It is likely that over 30 million tonnes of colliery waste were tipped at Lynemouth over seven decades, with the greatest volumes in the late 1950s, throughout the 1960s and 1970s and into the early 1980s.

Anecdotal evidence of behaviour of Lynemouth spoil beaches

Eagle *et al.* (1979) reported that the absence of coal in the sediments sampled on ‘control beaches’ north of Lynemouth indicated that dispersion from the shore tipping sites in Lynemouth Bay was predominantly southwards. Limpenny *et al.* (1992) reported that coal was recovered in relatively large quantities in core sediment samples taken at Newbiggin Bay, to the south, in 1993 – 1996, inferring some by-passing of the headlands and southwards transport. However, Nunny (1978) had earlier reported that coal was also eroded from outcrops naturally occurring on the seabed within Newbiggin Bay and it was impossible to differentiate this source from residual coal particles transported from the colliery waste at Lynemouth. Nonetheless, southward transport under severe storm action was acknowledged as a possibility.

Nunny (1978) reported on a field survey that was undertaken in October and November 1976 to identify transport pathways carrying colliery waste offshore and alongshore from the tipping zone. A series of sea bed grab samples, sea bed core samples and beach sediment samples were collected and were coupled with an analysis of physical processes and sediment transport dynamics. The freshly dumped waste was found to be very coarse, with the largest cobbles being around 100 mm in diameter and only around 6% of the sample being finer than 1 mm. Approximately 20% of the material was coal, either as loose particles or, more commonly, bound up within the larger sandstone pieces.

Cobbles near the high water mark were reported to be lag deposits. Most material greater than 200 mm remained in the

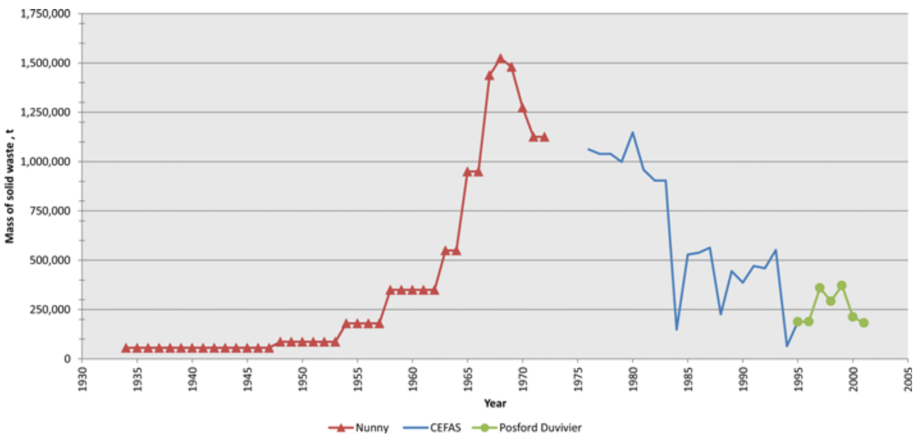

Fig. 4. Colliery waste disposal on the foreshore at Lynemouth from 1934 to the closure of Ellington Colliery in 2005. Data are from Nunny (1978) for 1934 – 1972, the Centre for Environment, Fisheries and Aquaculture Science (CEFAS, unpublished data, see ‘Acknowledgements and Funding’ section) for 1976 – 1994, and Posford Duvivier (2001) for 1995–August 2001. Note that data are missing for the periods 1973 – 1975 and 2002 – 2005.

lag deposit, while all material finer than about 4 mm was transported away. Thus around 40% of the minestone tipped was immediately redistributed during periods of high wave activity. At such times, the remaining cobbles underwent some movement, being edged landwards to the extreme high water mark, where they accumulated as storm deposits. The lower beach comprised finer gravel and coarse sand, which was capable of being moved by swash-zone wave action and which could be subject to modest longshore drift in a net southerly direction. The natural sand of Lynemouth Bay appeared as thin veneers at isolated localities and was believed by Nunny (1978) to be quite extensive in the immediate sub-tidal nearshore environment. In summer months, gentler wave action brought these sands onshore, depositing them as temporary veneers on the gravel beach, to be re-deposited seawards again during winter storms.

Shelter afforded by Snab Point, the headland at the northern end of the bay (Fig. 9), and by offshore ledges prevented the movement northwards of the coarser colliery waste. Consequently, the beach at the northern end of the bay comprised medium sands, although there are deposits of finer coal particles along the high water mark.

Towards the southern end of Lyne Sands (Fig. 9), the beach was covered by a plateau of consolidated waste protecting the backing cliffs and dunes. At the high-water mark, the waste formed a distinct ‘cliffed’ notch of about 0.5 m in height. Above the high-water mark, the back beach was composed of ridges of waste-derived gravels and cobbles up to several centimetres in diameter. The beach below mean high water was composed of finer waste material, resting on naturally occurring fine gravel and coarse sands.

Nunny (1978) also found that the nature of this coastline with its narrow range of naturally occurring beach sediment sizes, its uniform submarine slope, and a degree of indentation that caused diffracted waves to approach normal to the shore in many bays, simplified the movement of beach sediment. Temporal changes in wave height, period and direction remained the major factors influencing sediment transport, such changes primarily affecting onshore–offshore sediment movement rather than longshore drift. It was suggested by Nunny (1978) that of the estimated 70 – 90% of spoil transported onshore–offshore, most of the spoil moved offshore never passed seaward of around the 10 m Chart Datum sea bed contour, remaining in much shallower nearshore areas. In fact, more recent research has suggested that there is little sea bed elevation change, and hence little inferred sediment transport, seaward of 10 m below Ordnance Datum, indicating an even shallower limit on sediment transport (CH2M 2015). It is inferred that the proportion that was taken further offshore comprised the finest grain sizes of the colliery spoil. Wave-driven longshore drift to the south had previously been reported (Steers 1964), but was not considered to be a major process affecting sediment movements along this coastline. Whilst isolated storms could produce some movement, it seems more probable that each bay encloses its own ‘cell’ of beach sediment transport, with very little exchange between adjoining bays (Steers 1964). Material coarser than 180 µm will be rapidly transported to and fro along the beaches, and periodically moved offshore during storms to be returned to the beach during calmer weather. It was considered that only the very finest fractions of spoil (<180 µm) would be carried further out to sea. The net transport of any material put into suspension from the sea bed by wave activity will accordingly be affected by the residual drift of tidal currents, imposing a southward and offshore movement.

Posford Duvivier (2001) undertook beach surveying and visual condition assessments in 1998, 1999 and 2000 in the vicinity of Lynemouth power station. Minestone placement remained ongoing at that time at a location just north of the power station, forming a bund that acted as a sea defence. Results identified that the mean high water line north of the rock revetment (fronting the power station since construction of this sea defence in 1995) had retreated, but remained relatively stable to the south. The rate of change in the mean high water line, with reference to an earlier baseline survey from 1993, is presented in Table 2. An update of the rates of change, using coastal monitoring data, is presented later in this paper (see **Contemporary changes in the shoreline since the cessation of tipping**).

Observations from the Lynemouth rock revetment and revetment extension projects in 1995 and 2005 – 2006 indicated that the colliery spoil was essentially a fine-grained clayey material. Extracted colliery waste is granular with little water content, but when exposed to the sea, water is absorbed and the material expands and softens. If emplaced in any significant thickness, it becomes a medium soft clay. As such, it can erode relatively quickly in its original state, but is stabilized when transformed into a more consolidated form following exposure to sea water.

County Durham coastline

The collieries of the east County Durham coastline were opened in the 1900s, but during the decades that followed, the beaches and sea became fouled with waste dumped from the mines and raw sewage from pit villages (Somerville 2005). Deep mines were sunk at the coastal collieries of Dawdon, Easington, Horden and Blackhall (Fig. 1), with workings extending beneath the sea. Dumping of mine waste from these pits onto the beaches of County Durham began

Table 2. *Change in mean high water (MHW) line at Lynemouth from beach survey data*

Location	Description of change in MHW line between survey dates		
	1993 – 1998	1998 – 1999	1999 – 2000
Minestone disposal area in front of the coal stocking yard	12 – 25 m erosion	10 – 17 m accretion	15 – 25 m erosion
Power station	20 m erosion	4 m erosion	Position fixed by toe of rock revetment
Lyne Sands	No 1993 survey	9 m erosion	7 m accretion

Data from Posford Duvivier (2001).

around 1900, particularly between Seaham and Hartlepool at Dawdon Bankside (Fig. 5), Dawdon Blast Beach (Fig. 6), Easington, Horden (Fig. 7) and Blackhall (Beech & Paterson 1994). Tipping ceased in 1993 with the closure of Easington Colliery, and natural processes of erosion started to migrate the shoreline landwards. Erosion is ongoing and is expected to continue into the future, and will ultimately result in re-activated erosion of the backing cliffs.

Historical records of colliery spoil tipping

Colliery waste (minestone) was dumped on the beaches and sea bed off County Durham's coastline from as early as the 19th Century. The number of dumping sites increased up to the 1920s, and increased mechanization after the Second World War led to substantial increases in production of coal and associated colliery waste. The progression of tipping at beach dump sites is shown in Table 3.

Colliery waste at Dawdon was dumped at both Dawdon Bankside (Fig. 5) and Dawdon Blast Beach (Fig. 6). The accumulation of spoil formed an artificial beach in both locations, with the spoil beach at Blast Beach being some 140 m wide. This material effectively arrested coastal erosion of the sea cliffs at both sites, but also had undesired aesthetic and environmental impacts.

The disposal sites at Dawdon were used for waste from Dawdon, Hawthorn, South Hetton, Seaham and Vane Tempest collieries. Material was taken by rail to Nose's Point (Fig. 9), a headland separating the Bankside and Blast

Fig. 5. Dawdon Bankside (Seaham Fleet Rock sea stack in distance). Note the small slippages starting to occur in the sea cliffs as the spoil beach has now all but disappeared due to erosion.

Fig. 6. Dawdon Blast Beach. Note the stable sea cliffs to the rear of the wide but retreating spoil beach.

Fig. 7. Horden Spoil Beach. Note the wide spoil beach at the toe of the sea cliffs.

Table 3. *Reported progression of colliery spoil tipping on County Durham foreshore (Posford Duvivier 1993)*

Foreshore dump site	Commencement of tipping	Cessation of tipping
Dawdon Bankside	1910	1991
Dawdon Blast Beach	Pre 1900	1987
Easington	1920	1993
Horden	1922	1984
Blackhall	1924	1974

Beach foreshores, where it was tipped over the cliff and then spread by bulldozer. Waste at Easington, Horden and Blackhall was tipped directly onto the beach from aerial flights.

Much of the tipping occurred prior to the introduction of environmental regulation and therefore went undocumented. It has been estimated that around 40 million tonnes of colliery waste had been tipped in total on the County Durham beaches by 1970 (Hydraulics Research Station 1970). At the peak of tipping, in 1983, over 2.5 million tonnes of waste were tipped in one year. Other literature indicates that at least 100 million tonnes of colliery waste were dumped into the sea off County Durham, at both foreshore tipping grounds and in offshore dump sites (Durham Heritage Coast 2002).

CEFAS records of the 'volume of solids' tipped onto the shore between 1976 and 1995 are used to show the trends over this time (Fig. 8). It should be noted that all of the tipping at Blackhall went unrecorded before its cessation in 1974. Also, only the cumulative volume of solids tipped along the Durham coastline was recorded prior to 1985, but after that date the tipping at individual sites was recorded in addition to the cumulative total. By that time, tipping had ceased at Horden, so only deposits at Dawdon Blast Beach, Dawdon Bankside and Easington Foreshore are shown as individual quantities post-1985 in Figure 7.

Turning the Tide

In 1974, a decision was taken by the local (district and county) authorities to stop colliery waste tipping as soon as alternative means of disposal were found. By then, the coastline of County Durham was run-down and neglected after experiencing around a century of tipping. A management plan produced in 1982 (Durham County Council &

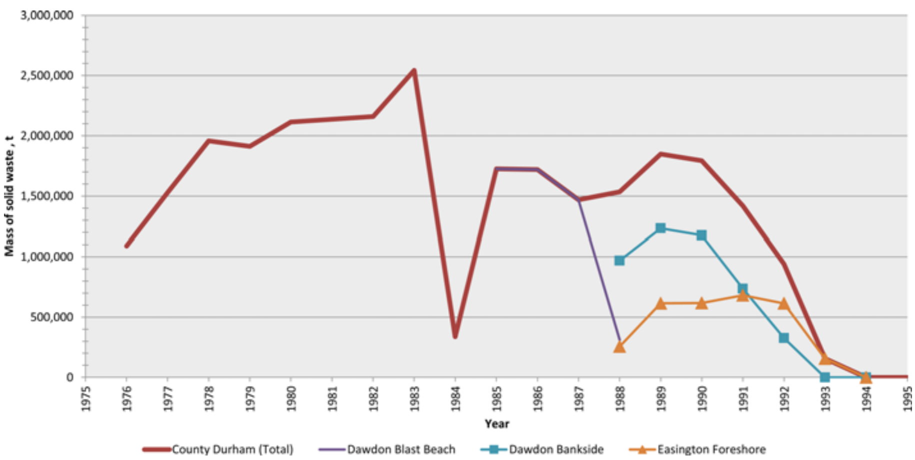

Fig. 8. Colliery waste disposal on the foreshore of County Durham (1976–1995).

Easington District Council 1982) advocated policies for cleaning-up the beaches. Some policies were implemented, but beach tipping continued. In 1990, it was confirmed that the authorities would not renew licences for dumping waste and colliery tailings after 1995. Tipping on the County Durham coastline actually stopped in 1993 as a result of pit closures.

When the end of tipping was in sight, a management plan was developed to return the shoreline to its natural character. A study was initiated to identify the management issues and potential impacts, both beneficial and adverse, of the cessation of tipping colliery waste on the beaches (Posford Duvivier Environment 1993). A crucial part of this work was to develop a comprehensive understanding of the shoreline processes and related characteristics of cliff erosion (Posford Duvivier 1993).

Following the cessation of tipping, marine erosion began to remove spoil from the beaches, bringing them back to their pre-tipping position over subsequent years and decades, whilst simultaneously dispersing eroded tipped spoil into the wider North Sea. As part of a programme to improve the environment and amenities of East Durham, the *Turning the Tide* project commenced in July 1997 and ran until March 2002. One of its aims was to improve the beaches along the 18 km coastline of County Durham by removing derelict structures (e.g. conveyors and the concrete towers), debris and rubbish. The work of the *Turning the Tide* project is now being continued by the Durham Heritage Coast.

Historical changes in the shorelines

For this paper, digital historic maps at 1:10 000 scale were georeferenced and analyzed in a Geographical Information System (GIS) for the Lynemouth frontage and for a large section of the County Durham coastline. These historic maps, covering dates in the 1860s, 1960s and the 1980s, were compared with the present day digital orthorectified Ordnance Survey (OS) maps to depict areas of change along the frontage. It should be noted that due to the mapping scales used and the inherent limitations on accuracy associated with both the georeferencing process itself and the digitizing of lines marked on historic charts, errors in mapping position of the order of ±10 m may be expected. Figure 9 is used to exemplify the changes observed, by reference to Lynemouth Bay in Northumberland and Blast Beach, Hawthorne Hive and Shippersea Bay in County Durham. It can be seen that the scale of changes in shoreline position is substantial and extends well beyond the potential errors in assessment due to georeferencing and digitizing, and can therefore be considered as representative of true historic changes.

Lynemouth

At Lynemouth, the 1865 shoreline followed an embayed alignment between adjacent rock headlands. The River Lyne flowed to the sea to the immediate south of Lyne Hill.

By 1966, the shape of the coastline had changed dramatically, with sediment infilling the previous embayment to create a more linear shoreline. The line of mean high water prograded seawards markedly through the whole bay, most especially in the vicinity of the mouth of the River Lyne and in Lyne Sands to the south, due to tipping of considerable quantities of colliery spoil. Two tipping conveyors were marked on the 1966 map as being present north of Lyne Hill.

At Lyne Hill, the high water mark moved 125 m seaward between 1865 and 1966. At the northern end of Lyne Sands, just south of the mouth of the River Lyne, the progradation was in excess of 400 m. Further south, along Lyne Sands, the high water marked moved seaward, leaving the dunes stranded.

By the 1980s, the shoreline had prograded further still through the whole bay, but again most markedly from Lyne Hill south along Lyne Sands. At the point of greatest change,

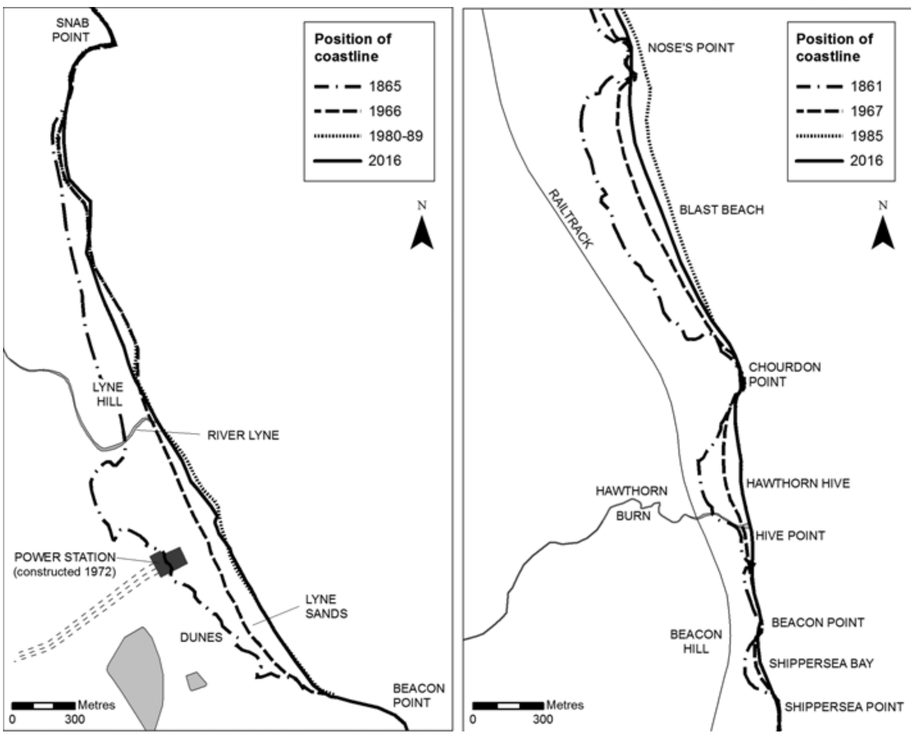

Fig. 9. Historical changes in shoreline position at Lynemouth Bay (left) and Blast Beach, Hawthorne Hive and Shippersea Bay in County Durham (right).

Table 4. *Summary of spoil tipping and historical shoreline changes at Lynemouth*

Epoch	Approximate mass tipped (tonnes)	Maximum change in shoreline position
1865 – 1966	6 million (Note that records began only in 1934 and therefore tipping between 1865 and 1933 is unreported)	400 m seaward advance
1966 to mid-1980s	18 million (Note data gap in records between 1973 and 1975 inclusive)	115 m seaward advance
mid-1980s to 2016	4 million (Note that there has been no tipping from 2001 to date)	25 m landward retreat

Table 5. *Summary of spoil tipping and historical shoreline changes at Blast Beach*

Epoch	Approximate mass tipped (tonnes)	Maximum change in shoreline position
1861 – 1967	Unknown (No records exist)	150 m seaward advance
1967 – 1985	Unknown (Note 15 million tonnes total tipped between 1976 and 1984 in the whole of County Durham)	115 m seaward advance
1985 – 2016	10 million (Note that there has been no tipping from 1992 to date)	75 m landward retreat

in the immediate vicinity of the mouth of the River Lyne, the high water mark moved seawards by around a further 115 m compared to the 1966 mapping, marking a progradation of just under 500 m at this point since 1865. By this time, Lynemouth power station had been constructed (in 1972) on reclaimed land at the northern end of Lyne Sands, covering part of the stranded dune links and part of the spoil beach.

By the time of the present-day OS mapping, the high water line had retreated landward by around 25 m at the point of discharge of the River Lyne and by a similar distance immediately in front of the power station. These historic changes are summarized in Table 4.

Durham

Changes along the Durham coastline are similar to those described for Lynemouth, with a pattern of initial substantial progradation of the shore followed by more recent recession since cessation of tipping. This is exemplified by Dawdon Blast Beach in Figure 9, but is common also for other frontages within the county.

In 1861, the foreshore now called Dawdon Blast Beach was a very well-defined embayment between the headlands of Nose's Point and Chourdon Point. Hawthorne Hive was a small natural bay between Chourdon Point and Hive Point and Shippersea Bay was similar between Beacon Point and Shippersea Point. In between the two bays was a short length of straight undeveloped cliff between Hive Point and Beacon Point. By the time of the 1967 mapping, colliery spoil tipping had advanced the mean high water line in Blast Beach from the toe of the cliffs to a position around 150 m seaward. Hawthorne Hive had become infilled with colliery waste transported from Blast Beach around Chourdon Point. This moved the line of high water seaward by over 100 m in Hawthorne Hive. The effect was slightly less pronounced in Shippersea Bay, due to its greater distance from the source of the colliery spoil, but nonetheless the high water mark was pushed seaward by over 50 m. In addition, a small colliery spoil beach developed in front of the straight section of cliffs between Hive Point and Beacon Point.

By 1985 a further 115 m of progradation had occurred in the centre of Blast Beach. This progradation resulted in

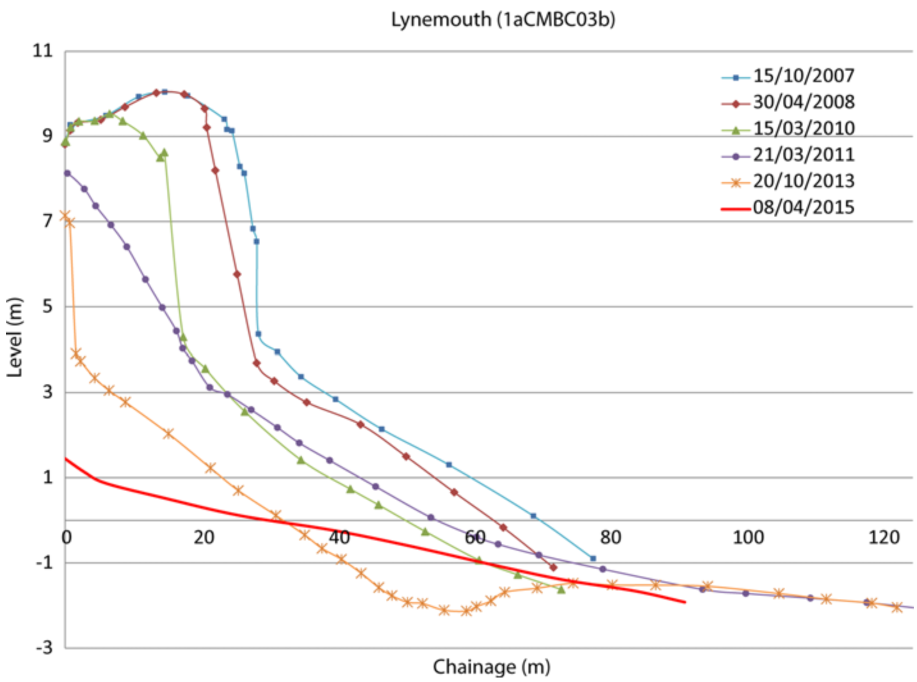

Fig. 10. Changes along a beach profile transect in Lynemouth Bay, 2007 – 2015. Note how each successive survey shows a progressive landward retreat of the spoil 'berm'.

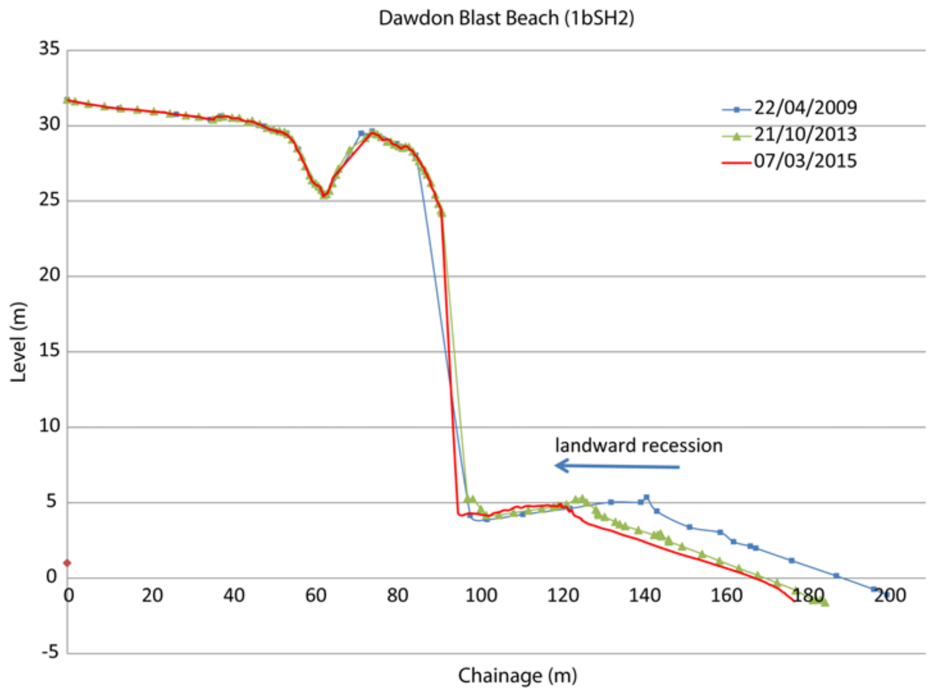

Fig. 11. Changes along a beach profile transect at Dawdon Blast Beach, 2009 – 2015. Note how each successive survey shows a progressive landward retreat of the spoil 'cliff'.

Nose's Point and, to a lesser extent, Chourdon Point becoming 'stranded' as headlands. Progradation of the high water mark also continued in Hawthorne Hive, where a total width of waste beach of over 180 m was present in the centre of the bay. Whilst the beach growth was more modest in Shippersea Bay, to a maximum width of around 80 m, the continued growth in these bays, and along the cliffs between them, indicated continued feed from the colliery spoil that was deposited in Blast Beach.

By the date of the present-day mapping, the high water line had migrated landwards by over 75 m in the north of Blast Beach, and around 40 m in the centre. The historic changes at Blast Beach are summarized in Table 5. To date, there has been minimal retreat in Hawthorne Hive and Shippersea Bay, presumably because these beaches are still being fed to an extent by spoil being eroded from Blast Beach.

Contemporary changes in the shoreline since the cessation of tipping

The Cell 1 Regional Coastal Monitoring Programme (Cooper *et al.* 2009) comprises a series of survey techniques designed to understand better contemporary changes in the shoreline of NE England. It covers the coastline within 'Coastal Cell 1' (as defined by Motyka & Brampton 1993) covering St. Abb's Head in southern Scotland (Berwickshire) to Flamborough Head in the East Riding of Yorkshire, England. The monitoring programme incorporates, amongst other

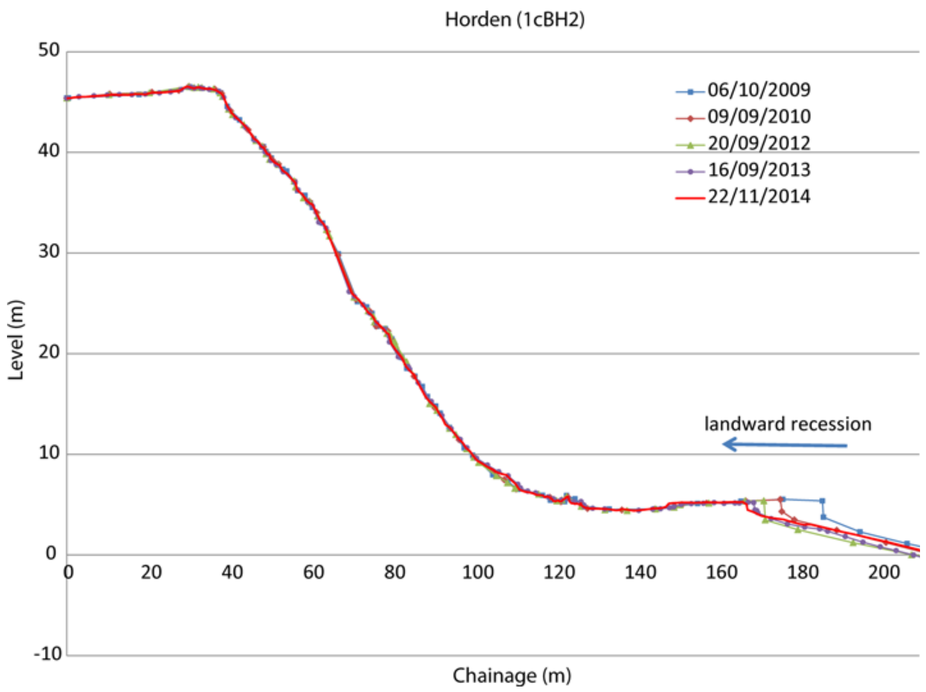

Fig. 12. Changes along a beach profile transect at Horden, 2009 – 2014. Note how each successive survey shows a progressive landward retreat of the spoil 'cliff'.

approaches, collection of beach profile survey data along a series of shore-perpendicular transects. These include transects within both Lynemouth Bay and along the County Durham coastline.

Transect 1aCMBC03b in Lynemouth Bay was first surveyed in 2007 and is located in the area of most recent colliery spoil tipping, just to the north of Lynemouth Power Station (Fig. 1). The successive surveys have shown a progressive landward retreat of the 'berm' of the spoil beach of almost 30 m since 2007 (Fig. 10).

Similar recessional trends have been observed along the County Durham coastline. At Dawdon Blast Beach, for example, the survey transect 1bSH2 (Fig. 1) has exhibited measurable change. The width of colliery spoil has retreated by around 20 m between 2008 and 2015 (Fig. 11). The trend has been of persistent retreat over a number of years, rather than losses due to any single storm event. There is a remaining width of around only 25 m in front of the (present-day) relict cliffs.

Similarly, transect 1cBH2 at Horden (Figs 1 and 12) has also shown measurable change in the width of colliery spoil, persistently retreating between successive surveys since records began in 2009. In total, the edge of the spoil has retreated by around 20 m between 2009 and 2014. There is a remaining width of spoil of around 50 m at this point along the frontage.

It is likely that the remaining widths of colliery spoil at both Dawdon Blast Beach and Horden will be removed over the order of several years (rather than several decades) and that cliff erosion due to marine processes will become reactivated.

Conclusions

This paper has investigated the historical legacy of colliery spoil tipping at Lynemouth Bay in Northumberland and at various foreshore sites in County Durham. A particular focus has been on understanding the artificial supply of sediment to the foreshores by spoil tipping, the associated historical effects on shoreline behaviour, and the effects of the subsequent cessation of tipping. The approach adopted was Historical Trends Analysis (HTA), which is a method for interrogating series of data to identify trends and rates of change in a shoreline over time, based upon analysis of historical maps, charts, aerial photographs and beach profile surveys and a review of available literature sources.

The HTA identified that large quantities of solid wastes were dumped for many years from a number of sources, either directly onto the shore or some miles off parts of the NE coast of England. Waste from some coastal collieries in Northumberland and Durham were tipped directly onto foreshore tipping sites where they have been dispersed by wave action. Wastes from other collieries were dumped at offshore disposal sites. In most cases, dumping started well before statutory controls came into force in the UK in 1974. Since that date, disposal of these wastes has been regulated under licence. It is estimated that around 30 million tonnes of colliery waste (minestone) from Lynemouth and Ellington collieries were tipped at foreshore disposal sites in Lynemouth Bay between 1934 and 2005, with over 1.5 million tonnes tipped at its peak in one year (1968). Over 100 million tonnes of colliery waste (minestone) were tipped along the County Durham coastline, either at offshore disposal sites or at foreshore disposal sites. The foreshore tipping of waste from Dawdon, Easington, Horden and Blackhall Collieries occurred from the early 20th Century to 1993 when the last colliery (Easington) closed. At its peak, over 2.5 million tonnes were tipped in one year (1983).

In all cases, the tipping of waste resulted in significant progradation (seaward movement) of the shoreline and infilling of the bays to form wide spoil beaches as a 'terrace' on the upper beach. In Lynemouth Bay, this occurred to such an extent that reclaimed land was developed for construction of the Lynemouth power station, and along the County Durham coastline the spoil beaches became so wide that the backing cliffs became separated from marine action and are currently relict features. Due to geochemical processes that occurred after extraction of the spoil and its placement on the foreshore, its composition has altered from a granular state to a more consolidated clayey condition that is more resistant to erosion than its constituent grains.

When the colliery waste was tipped, some was quickly eroded and transported seawards to the nearshore zone (within the 10 m sea bed contour). For many decades, ongoing tipping compensated for this 'loss' from the shoreline. Material moved to the shallow nearshore zone would then become further broken up into smaller particles by marine action and, when sufficiently small in grain size, transported by tidal currents in the direction of the net southerly current. Larger grain sizes would tend to remain on the beach as lag boulder, cobble or gravel deposits.

Some alongshore transport of material also occurred, particularly when the spoil beaches had increased in width so much that the high water mark extended beyond the rock headlands that intersect adjacent bays. This was most notable along the County Durham frontage where both Hawthorne Hive and Shippersea Bay, both located to the south of Dawdon Blast Beach, became infilled with colliery spoil, despite not being tipping sites.

Since the cessation of tipping, the shoreline in all former tipping areas has been retreating. This has caused retreat of the high water line to a position landward of the headlands, meaning that potential for 'bay to bay' transport of remaining spoil beaches due to longshore drift has reduced.

The ongoing retreat of the shoreline since cessation of spoil tipping on the foreshores has caused particular problems in Lynemouth Bay, where a rock revetment had to be constructed in 1995 in front of the power station for purposes of sea defence, and was extended in 2005 around the adjacent coal-stocking yard.

In County Durham, beach profile surveys have shown that colliery spoil beaches retreated rapidly (20 m/year) in the initial 2 – 5 years after the cessation of tipping, but the rate then reduced significantly, to around 0.5 – 2.0 m/year, as the erosion encroached into the older, consolidated spoil. Ongoing beach surveys and walk-over visual inspections are monitoring the ongoing retreat of the spoil beaches, which is clearly measureable.

Cliffs that are currently protected by spoil beaches could retreat at rates of up to 0.3 m/year when marine processes are re-activated at the toe of the cliffs. Initially, the rate could be higher as accelerated erosion is likely to occur in the exposed rock face, which, though isolated from the sea for many years, has weakened through weathering processes. Along Dawdon Bankside, the residual colliery spoil beach is now so narrow that parts of the backing cliffs have started to experience slumping in recent years.

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