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THE ROLE OF LONG-TERM LANDSCAPE PHOTOGRAPHY AS A TOOL IN DUNE MANAGEMENT

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Abstract. Attitudes to maintaining dune diversity are changing under the realization that existing dune stabilization techniques are fixing dune landscapes, causing 'coastal squeeze' and loss of habitat as shorelines retreat. Instead, it is recommended that a natural, dynamic, migrating dune system is much more appropriate and that blown, unstable sands are encouraged to act as mobile coastal defence barriers. Lack of appropriate monitoring techniques has limited progress in understanding the role of sediment dynamics in dune environments over long timescales. Therefore, this paper outlines the role of straightforward and inexpensive photography, from fixed points and angles, as a useful approach to long-term, decadal monitoring of the evolution and migration of dynamic dune landforms. The case study, on the Morfa Dyffryn dunes, Gwynedd, mid-Wales, United Kingdom (National Grid Reference SH563240), identified particularly dynamic mobile foredunes, with cyclical morphological development, paralleling to an overall landward recession. A cyclical trend of sand encroachment, followed by stabilization with growing vegetation, is documented for semi-fixed dune pastures, while the hind dunes remained stable. A general relationship between foredune morphology and erosion/accretion processes was established, offering the prospect of predicting future dune morphological changes in other dune systems, if increased blown sand activity is encouraged as a management technique.

Keywords: coastal dune management, photographic survey, erosion/accretion processes, pedogenic development, coastal change.

1. Introduction

Sand dune systems are a vital component of coastal landscapes, indirectly acting as natural coastal defences through offering resistance to wave attack (Bird 1993, 2000; Woodroffe 2002; Pečiulienė *et al.* 2005; Saye *et al.* 2005). Sand dune features are composed of loose sediment that can be mobilized during storm events as part of a cyclical process (Pethick 1984, 2001; Goldsmith 1985; Tsoar 2005; Anthony *et al.* 2006). Deposition of eroded sand onto the beach increases energy dissipation, subsequently reducing further erosion. Sediment is then transported back up the steep windward dune face, over the ridge, to accumulate on the gentle leeward slope through a natural process termed dune 'roll over' (Pethick 1984; Houston 1992).

Until the late 19th century, dune environments in north-west Europe, including Britain, were used for cultivation and grazing, overexploitation of which would reactivate sandblow (Greswell 1953). Perceptions turned to controlling blown sand and halting sand drift in an attempt to maintain the natural dune barrier ridge, which led to stabilization techniques, including planting of conifers and scrub species, such as sea buckthorn (Hippophae rhamnoides) (Wheeler *et al.* 1993). However, over-stabilization of dunes can result in 'coastal squeeze' and loss of habitat where the landward position is fixed, i.e. afforested dunes (Doody 2001; Orford and Pethick 2006).

Recently, however, a new attitude to dune management has evolved, with the realization that effects of 'coastal squeeze' can be overcome by abandoning stabilization techniques and allowing dune activity (Houston 1992; Pethick 2001; Orford and Pethick 2006). Instead of creating artificial fixed dune environments, increasing grazing pressure and encouraged public access is recommended, to subsequently cause blowouts and mobilize sand, maintaining characteristics of a migrating dune landscape. While frontal dune erosion inevitably leads to loss of habitat area it may also bring benefits in the form of geomorphological and ecological dynamism (Pye 2001; Orford and Pethick 2006).

A lack of appropriate monitoring techniques has limited progress in understanding the role of sediment dynamics (Šurda *et al*. 2007) in dune environments. The extent of coastal aeolian processes, coupled with limited vegetation cover and the high erodibility of dune sands, make coastal dunes susceptible to rapid morphological adjustments (e.g. van der Meulen 1990; Carter 1991; Pye and Neal 1993; Anderson and Walker 2006). In many disciplines, geomorphologists rely on low-resolution, frequently-updated field monitoring, such as repeat photography (e.g. Harvey 1977). For instance, this technique was used to analyze forest changes during the past century in the San Juan Mountains of Colorado, USA (Zier and Baker 2006), and widespread glacier recession was documented using repeat photography in Patagonia (Masiokas *et al.* 2007). Repeat ground photography can show, in a simple yet powerful way, the impacts of recent coastal changes on these sensitive dune environments. Changes in foreshore level and frontal dune erosion/accretion have been recorded on some British coasts since the 1950s by measurements relative to fixed points (e.g. the North Norfolk coast, Eastern England (Livingstone *et al.* 1999) and the Sefton coast of North-West England (Saye *et al.* 2005)). On a larger scale, an automated video camera system has been deployed to document erosion of dunes, barrier islands and inlet channels on the Algarve coast of Portugal (Morris *et al.* 2001).

2. Methods

2.1. Case study area

This paper outlines the success of monitoring dune dynamics, through long-term landscape photography, on a section of the Morfa Dyffryn dunes, Gwynedd, Mid Wales, United Kingdom (National Grid Reference: SH563240) (Fig. 1) and highlights its potential role in future dune management strategies. Annual photographic surveys of dune morphology, since June 1988 to the present day, have been continuing as an ongoing programme of morphological monitoring (Fullen and Moore 1999; Millington *et al.* 2008). Morfa Dyffryn is a 10.6 km^2 transgressive dunefield, in which the parabolic dunes lie sub-parallel to the prevailing south-westerly winds. Rates of parabolic dune migration in this area are not currently known, but are believed to be comparable to dune migration rates at Aberffraw, Anglesey, North Wales, ranging from 0–3.6 m year^{-1}, with a mean migration rate of 1 m year^{-1} (Bailey and Bristow 2004). However, these migration rates are low compared with the parabolic dunefield of Newborough Warren, Anglesey, where migration rates of 1.5–6.7 m year^{-1} over a 3-year period were determined (Ranwell 1958).

2.2. Fixed-Point-Photography (FPP)

Three monitoring stations were selected along a transect, oblique to the shore, for FPP analysis: (i) Station 1, upper beach (SH 56685 23087); (ii) Station 2, mobile dune peak (SH 56725 23142) and (iii) Station 3, fixed dune (SH 56828 23204). Photographs were taken from fixed angles, determined using a prismatic compass. Occasionally the view from the previous year's photo point was obscured by vegetation/dune height growth. If an alternative clearer dune-view could not be obtained within ~3 m, the photo was not used.

Fig. 1. Location of Morfa Dyffryn within the British Isles

The expanding database now contains 24 photosets and an archive of 215 photographs. The systematic evaluation of 17 photosets was initially combined with field observations to identify trends in coastal dune change. Exposure of a Second World War bunker in 1995 facilitated the addition of a further four photosets, and a further two sets were added in 2007, following field observations of an advancing pebble ridge. Photosets predating 2006 were in slide format, which have been scanned at high resolution for digital analysis. Image-processing software (Adobe Photoshop CS2 version 9, 2005) was used to digitally match photosets by layering one photo over the other for alignment.

Within a photo comparison, morphological features were analysed for increase, decrease or stability, based on an already successful methodology (Zier and Baker 2006). An increase in extent was documented when a major dune morphological feature or vegetation type clearly occurred in new areas not occupied in the previous year's photograph. A decrease in extent was recorded when the dune's morphological feature or vegetation type clearly occupied less area than in the previous year's photograph. The degree of increase or decrease was classified as either moderate or extensive. However, the distinction between moderate and extensive changes is subjective, and estimations of area change are difficult. Vertical dune growth can sometimes block the view of areas, making them appear smaller due to sand encroachment.

Fig. 2. Photographs of view from beach to foredune. Note the dune deflation and destruction of the fence, followed by accretion and then deflation of the dune 'pyramidal peak' (Station 2). Also note development of the embryo foredune and colonization by *Ammophila arenaria* in 1994. This appears much less established in 2006

Fig. 3a. View directly in front of the war bunker. In 1995, a Second World War bunker became visible in the foredunes and provided a new fixed point. Observe the deflation of sand

Fig. 3b. View from the south side of the bunker. Observe the exposure of the south-facing window and undercutting of the concrete platform

Fig. 4. View west from Station 3. Deflated sand from the foredune was deposited on the dune slack, burying dune meadow vegetation. Vegetation then recolonized the 'sand apron'. Pedological analyses of soil profiles beneath a willow (*Salix cinerea*) copse suggest cyclical patterns of dune deflation and stabilization. Note that otherwise the hind dunes remained morphologically stable

3. Results

The mobile foredunes are particularly dynamic and thus they migrated landwards during the first 10 years of monitoring (1988–1998). Extensive dune deflation and subsequent burial of a fence is evident in the photographic sequence shown in Fig. 2.

The dominant landscape feature in 1988 is clearly a dune peak. An extensive change occurred in 1990, due to a later phase of deflation, as the dune pyramidal peak was replaced by an open dune field, followed by accretion of the same dune peak again within a ~6 year cycle period. Rapid colonization by marram grass (*Ammophila arenaria*), during the accretion phase beginning in 1994, has encouraged foredune height growth and subsequent stabilization. This stabilization of deflated sand supported embryo dune development seaward of the main foredune landscape, up until mid-way through the first decade of the millennium, when a decrease in the extent of these embryo dunes could be observed. However, the overall foredune status during the last decade is considered stable, as only minor subtle changes in the embryo dunes are visible. In contrast, the morphological shape and boundary locations between bare sand and dune vegetation have remained unchanged since 1998. Further evidence of landward recession of the foredunes is provided by the appearance of a Second World War bunker in 1995. Fig. 3a and 3b show the progressive exposure of the south-facing window and subsequent sand deflation adjacent to and beneath the bunker.

The fixed hind dunes remained morphologically stable throughout the monitoring survey and any areas of bare sand were progressively colonized by marram grass (Fig. 4). A large expanse of dune meadow, containing typical species such as Creeping willow (*Salix repens*) and Fen sallow willow (*Salix cinerea*), occurred behind the main foredune landscape. This area, however, underwent rapid burial following a period of sand encroachment in 1990, which subsequently became re-colonized and stabilized by marram grass by 1996. This is considered a moderate change, as the sand apron is gradually re-colonized by dune meadow year-by-year. However, differences between 2001 and 2006 photographs are considered extensive, as the dune meadow appears to be completely recovered from the initial blowout event.

4. Discussion

4.1. Dune dynamics

Previous studies have identified that changes in beach morphology can suggest impending changes in the erosion/accretion status and morphology of frontal dunes (Saye *et al.* 2005). For instance, analysis of topographic beach profile data on the Sefton coast, northwest England, confirmed changes in beach morphology and provided an indicator of the onset of frontal dune erosion (Pye and Neal 1994). At Morfa Dyffryn the disappearance of the dune peak in 1990 is an indication of the redeposition of aeolian derived sand in the hind dunes. Furthermore, identification of upper beach embryo dune accretion, in 1994 and 2001, coincides with the redevelopment of the dune peak in the foredunes. The dune peak, in the centre of a blowout environment, appeared to grow in height between 1990 and 1994, and again in 2001. This was a result of aeolian-derived sand, from a positive beach and foredune budget, moving into the gap and being trapped by vegetation. However, successive embryo dune colonization by marram grass appeared to signify a change from stability to erosion in the foredunes and subsequent deflation of the dune peak in 1996, possibly as a result of a negative upper beach sediment budget, due to limited availability of loose sand. Sand deflation at this time is also evident by the exposure of the bunker in 1995. A conceptual model based on sediment budget has been proposed by Psuty (1992), which relates dune morphology to shoreline dynamics and dune forming factors. Therefore, two sediment budget situations, taken from four possible situations in this existing model, are evident for this part of the coast:

i. Negative beach and foredune budget, associated with washover, or foredune attenuation (featuring blowouts, parabolic re-entrants or hummocks).
ii. Negative beach budget, positive foredune budget, associated with foredune development, with maximum foredune height occurring where the beach is slightly erosional.

It is likely that the dune peak formation is associated with stabilization and vegetation colonization. However, it is a 'chicken-and-egg' problem whether the subsequent deflation of the peak is a result of embryo dune building and, therefore, a lack of sediment in the foredunes, or whether it is the onset of erosion creating embryo dunes out of sediment derived from the dune peak. A similar problem was encountered on the north coast of Denmark, where it could not be determined whether steepening of a shoreface was a result of onshore bar migration and landward sediment transfers, or whether onshore bar migration had been caused by an increasing shoreface slope (Aagaard *et al.* 2004). Since migration processes acting on dynamic dune systems are determined by wind direction relative to dune alignment (Tsoar *et al.* 2004), it would seem more likely that deflation and accretion of the dune peak is the outcome of at least two, asymmetric, erosive wind directions, one of which is more dominant and effective, creating a slip face on the lee side of the peak.

Initial analyses of soil profiles beneath the dune pasture suggest cyclical morphological development, alternating between phases of deflation and stabilization (Fullen and Moore 1999). Cu horizons (weathered parent material) are indicative of periods of dune instability and domination by aeolian processes, which subsequently become modified to Ah horizons (mixed mineral and organic matter) during periods of re-vegetation and stability (Leatherman 1979).

Overall, comparisons reveal that over the past two decades the environmental conditions in the region have clearly favoured accumulation over deflation in the mass balance of these dunes, with new foredunes developing from embryo dunes while former foredune ridges become vegetated and stable.

4.2. Management implications

It is widely accepted that dunes do not 'roll-over' or migrate for any great distance or timescale. The crest of a developing foredune may migrate landwards as a result of sand eroded from the top of the dune ridge, and subsequent deposition on the lee slope, but this is halted once the stationary vegetated hind dune ridges are met (Pethick 1984). For parabolic dunes, such as in the Morfa Dyffryn system, migration of the dune peak, which is readily identifiable in the photographs, could be used to measure overall migration rates and the cessation of dune mobility. However, it is possible for the morphology to change so as it is no longer possible to identify the same morphological feature between several photographs.

Parabolic dune landscapes, along with associated slack environments, are considered worthy of protection (Pethick 2001) in north-west Europe, due to their specific floral and faunal habitats. However, rapid vegetation colonization has decreased the potential of the Morfa Dyffryn dunes to maintain their dynamic landscape, and dune slacks are few. Despite this, the cessation of a migrating dune ridge by fixed vegetation cover can be overcome by the encouragement of grazing or trampling pressure, sand can advance from the area and a blowout may be formed. Eroded sand is transported down-wind and eventually deposited seaward of vegetated dunes. While the vegetated ridges of the blowout remain stationary, the former parallel ridge develops into a classic parabolic U-shape, typical of dynamic parabolic dune landscapes. As increased grazing pressure is maintained, erosion may meet the water-table and create a dune hollow or slack, which is an essential component of dune habitat diversity. It is extremely important, however, to encourage dune migration to isolated areas of vegetation removal and erosion, as severe pressures may result in the development of large transgressive sand sheets burying natural dune topography.

5. Conclusions

Repeated photography comparisons of sand dune dynamics provide baseline information about the long-term behaviour of local dune sedimentary systems. Evidence has documented two decades of coastal dune change that displays remarkable stability in the hind dunes, extensive invasions of meadow vegetation on the fixed dunes, cycles of sand encroachments on the mobile dunes, and substantial growth and subsequent deflation of the foredunes. The cost effective and time efficient survey illustrates a general cyclical relationship between upper beach dynamics, dune morphology, and erosion/accretion processes, which can inform the process of shoreline management. Despite the dune system showing considerable capacity for recovery, coastal managers, who intend to consider dune reactivation, segmentation and habitat reduction as the basis of future coastal evolution and planning, must ensure that destabilization is controlled and does not result in transgressive sheet erosion. When coupled with existing beach monitoring (Pye and Neal 1994), this survey technique could advance understanding of beach-dune dynamics and sedimentary budgets, if increased blown sand activity is to be encouraged as a management technique.

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ILGALAIKIS KRAŠTOVAIZDŽIO FOTOGRAFAVIMAS KAIP PRIEMONĖ NUMATANT KOPŲ VALDYMĄ

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Santrauka

Požiūris išlaikyti kopų įvairovę kinta, suvokiant, kad esamos kopų stabilizavimo priemonės, formuojant kopų kraštovaizdį, nepadeda išvengti pajūrio ruožo susiaurėjimo ir arealo praradimo atsitraukiant kranto linijai. Kita vertus, rekomenduojama išsaugoti natūralią dinamišką ir migruojančią kopų sistemą, kad nupustomi labilūs smėliai atliktų mobilių kranto apsaugos barjerų funkciją. Dėl tinkamų monitoringo priemonių trūkumo sulėtėjo patirties apie ilgalaikę nuosėdų dinamiką kopų aplinkoje kaupimas. Darbe aprašomas tiesioginis ir didelių išlaidų nereikalaujantis fotografijos metodas, kuris galėtų būti taikomas minėtoms problemoms spręsti. Metodas pagrįstas fotografavimu fiksuotuose taškuose ir tomis pačiomis kryptimis. Tai gali būti naudingas būdas ilgalaikiam monitoringui – stebėti dinaminių kopų sausumos darinių migraciją dešimtmečius. Tiriamoji vieta – Morfa Dyffryn kopos, Gwynedd, Velso vidurinėje dalyje Jungtinėje Karalystėje (nacionalinėje koordinačių sistemoje SH563240). Tai ypač dinamiškos priešakinės kopos. Joms būdinga cikliška morfologinė raida, prilygstanti bendrajam atsitraukimui iš sausumo pusės. Cikliška smėlio įsibrovimo tendencija, po kurio vyksta augalijos stabilizavimasis, būdinga pusiau sutvirtintoms kopoms, kai užnugarinės kopos lieka stabilios. Darbe nustatytos bendros sąsajos tarp priešakinių kopų morfologijos ir erozijos/akrecijos procesų, siūlomas morfologinių pokyčių numatymo būdas, kuris galėtų tapti valdymo priemone ir kitose kopų sistemose, kur smėlis ypač pustomas.

Reikšminiai žodžiai: pakrantės kopų valdymas, fotografinė apžvalga, erozijos/akrecijos procesai, pedogeninis vystymas, pakrantės kitimas.

МНОГОЛЕТНЕЕ ФОТОГРАФИРОВАНИЕ ЛАНДШАФТА КАК СПОСОБ СЛЕЖЕНИЯ ЗА ДЮНАМИ

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Р е з ю м е

Мнение о том, как сохранить разнообразие дюн, меняется, если принять во внимание, что существующие способы стабилизации дюн формируют ландшафт с дюнами, „сжимают“ приморье и теряют ареал из-за отступления линии берега. С другой стороны, рекомендуется сохранить естественную, динамичную и мигрирующую систему, чтобы сдуваемые, подвижные пески служили мобильными барьерами для защиты берега. Из-за нехватки соответствующих средств мониторинга замедлилось получение сведений о многолетней динамике отложений в среде дюн. С целью восполнить пробел в статье описывается не требующий больших затрат метод фотографирования. Он основан на фотографировании в фиксированных точках и в тех же направлениях и может стать полезным способом осуществления многолетнего мониторинга миграции динамичных дюн. Исследования проводились в динамичных передних дюнах Morfa Dyffryn, Gwynedd, в средней части Уэльса в Англии (в Национальной системе координат SH563240). Для них характерно цикличное морфологическое развитие, соответствующее общему отступлению со стороны суши. Цикличная тенденция наступления песка, после чего стабилизируется растительность, характерна для отчасти укрепленных дюн в том случае, если задние дюны остаются стабильными. Установлена связь между процессами морфологии передних дюн и эрозии/аккреции, предложен способ предвидения морфологических изменений в качестве средства управления процессом и в других системах дюн, в которых усилилась деятельность подвижного песка.

Ключевые слова: управление процессами, происходящими в прибрежных дюнах, фотографический обзор, процессы эрозии⁄аккреции, педогенное развитие, изменение берегов.

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