



MANAGEMENT of Natura 2000 habitats

Humid dune slacks

2190

Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora

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21 – Sea dunes of the Atlantic, North Sea and Baltic coasts

EUNIS classification:
B1.8 - Moist and wet dune slacks

*Dune slack on Sefton Coast, northwest England. Conditions for *Petalophyllum ralfsii* maintained by rabbit grazing and trampling. Photo: John Houston*

Summary

Humid dune slacks represent the wetland component of dune systems, usually where the underlying water table reaches the surface. There are two main types. Primary dune slacks run parallel to a dune coastline and are formed when a developing sand ridge cuts off a portion of beach. Secondary dune slacks are formed by the landward movement of dune ridges over stable wet sand at the watertable. Dune slacks appear as flat valleys in the dune system, usually rich in species and associated with other wetland habitats. European vegetation classifications recognise a succession of slack types from bare damp sand to wet slacks dominated by trees and shrubs. The characteristic species of slacks are forms of dwarf willow, most commonly creeping willow. A number of rare species are associated with dune slacks including the fen orchid, petalwort (a bryophyte) and the natterjack toad.

The principal threats to the wetland habitats are water abstraction and drainage, a lack of natural dynamics leading to few 'embryo' slacks, under-grazing and scrub development. The natural formation of young primary slacks is also affected by shoreline management policies and coastal works. Climate change could pose a significant threat to the series of dune slacks in Europe. Most have been formed by natural sand movement but now lie within more stable dune systems. If water tables fall, as predicted in some areas, the habitat could be left 'high and dry'.

Most of the scientific research and published experience of management comes from the Netherlands, Belgium, France and the United Kingdom where there have been particular concerns about scrub invasion (especially by sea buckthorn) and the threats to rare plants. Applied techniques include scrub cutting, mowing, grazing, turf-stripping and re-wetting. Several restoration projects developed mowing regimes to maintain the low swards required by species such as fen orchid. Mowing can prolong the younger species-rich stage of slack succession but cannot reverse the process. On sites with a mosaic of habitats grazing is the preferred management tool where the management of dune slacks can be integrated with a grazing plan for the whole system.

Slacks can be 'created' by turf-stripping and removal of nutrient-rich soil. But such projects need carefully planning if they are to succeed. An evaluation of projects found that it was difficult to maintain species-richness without a mowing regime. Dune slacks remain a particularly threatened habitat at the European level.

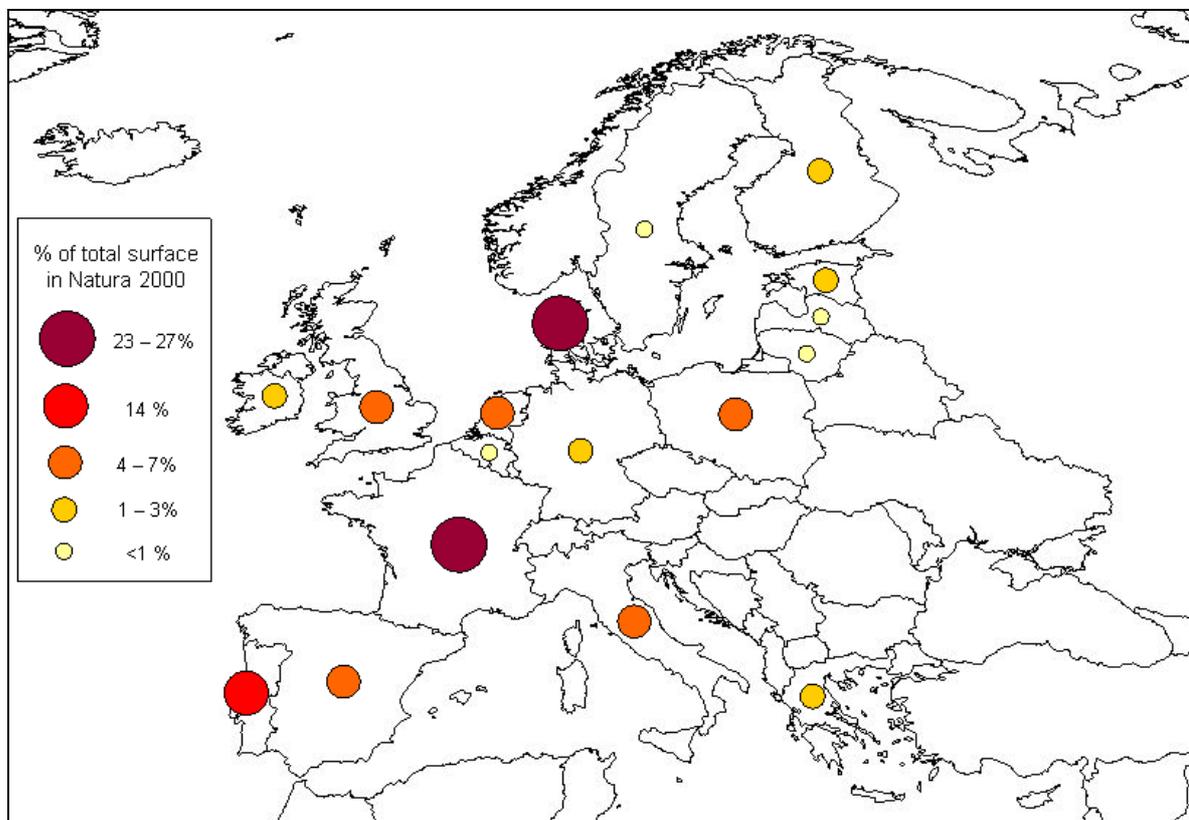
1. Description of habitat and related species

Humid dune slacks are a component of most large, dynamic or previously dynamic, dune systems. They are damp or wet hollows left between dunes where the groundwater reaches or approaches the surface of the sand. Their most distinguishing feature is a seasonally fluctuating water table which usually reaches a maximum in winter and spring and drops in summer.

It is recommended that this document is read in conjunction with that for fixed dunes (*2130) as some of the issues and management advice are common to both.

Distribution

Humid dune slacks are found throughout the coastal zone of the EU but are only locally abundant. They form an integral part of the extensive dune systems of the Atlantic biogeographical region.



Percentage distribution of the total surface of humid dune slacks in Natura 2000

Humid dune slacks in Natura 2000 sites

The following data have been extracted from the Natura 2000 Network database, elaborated by the European Commission with data updated on December 2006. The surface was estimated on the basis of the habitat cover indicated for each protected site and should be considered only as indicative of the habitat surface included in Natura 2000.

Biogeographical region	N° of sites	Estimated surface in Natura 2000 (ha)	% of total surface in Natura 2000
Atlantic	124	13,029	44.3
Mediterranean	42	8,155	27.7
Continental	52	7,113	24.2
Boreal	27	1,113	3.8
Countries	N° of sites	Estimated surface in Natura 2000 (ha)	% of total surface in Natura 2000
Denmark	33	7,788	26.5
France	50	7,003	23.6
Portugal	6	4,109	14.0
Netherlands	15	1,909	6.5
Italy	25	1,705	5.8
Spain	8	1,443	4.9
Poland	7	1,412	4.8
United Kingdom	25	1,254	4.3
Germany	19	643	2.2
Ireland	15	642	2.2
Estonia	8	522	1.8
Finland	7	367	1.2
Greece	8	300	1.05
Sweden	14	212	0.7
Latvia	3	49	0.2
Belgium	1	37	0.1
Lithuania	1	15	0.05
TOTAL	245	29,410	100

Main habitat features, ecology and variability

Two types of dune slack are distinguished on the basis of their geomorphological history. Primary dune slacks may be formed in accreting conditions when an area of the upper beach is enclosed by the development seaward of a new dune ridge. Slacks thus formed are often long and narrow and run parallel to the shore. Primary dune slacks may also be open-ended retaining a connection to the sea which allows flooding on the highest tides. Such slacks display a gradient of habitat types relating to salinity and frequency of tidal incursion. The perseverance of salt-marsh species such as *Glaux maritima* (sea milkwort) in humid dune slacks in the Atlantic region is a likely indicator of a recent link to the sea.

Secondary dune slacks are formed by wind eroded depressions in the dune system or in eroding systems by the landward movement of dune ridges over stable wet sand at the water table. Although formed by the same process the scale may vary from a few square metres of damp ground to large parabolic blowouts covering many hectares.

On exposed Atlantic coasts the prevailing westerly winds tend to encourage the development of high mobile dunes with *Ammophila arenaria* (marram grass). Although these become more fixed over time, erosive processes may enlarge the smallest of bare patches into blowouts which migrate in the direction of the prevailing wind. Wind can scour dry sand from a blow-out until the underlying water table is reached. As wind cannot further erode the damp sand the energy goes into pushing the dry sand ridge further down-wind, leaving in its wake a relatively flat damp surface: an embryonic secondary dune slack.

Seasonal and decadal fluctuations in water levels may further encourage the development of the slack. The medium-term fluctuations are important: in active, dynamic, dunes a run of 'dry' years will allow slacks to deepen to form a new series of wet slacks in the 'wet' years.

In general, sand is initially calcareous (from the input of shelly material) and the groundwater is more or less base-rich. The infiltration of rainwater leads to base-rich conditions, since calcium carbonate (CaCO₃) is dissolved in the rooting zone almost immediately. However, where initial lime content is low (e.g. on the Wadden Islands) the rapid decalcification will lead to more acid conditions.

Low nutrient levels deter the establishment of competitors and lead to high species diversity. Slack features may be maintained at least partly by disturbances, including fluctuations in the water table, blown sand, the effects of nutrient limitation and grazing.

Vegetation development is strongly associated with the average depth and seasonal fluctuation of the water table and the water-holding properties of the sand. Studies (by Ranwell 1972 and others) found that sand is saturated for about 10-15 cm above the water table and that capillary action carried substantial amounts of water up to 45 cm above it. The water table has little influence on the moisture content of sand 1m above it. The depth and duration of winter flooding, and the severity of summer drought, are likely to be important determinants of slack community structure (Davy *et al.* 2006). Ranwell (1959) described slacks as either wet in which the free water table never fell below 1m of the ground level in any season, or dry, in which the free water table in summer was always 1-2m below ground level.

Main subtypes identified

In a general conceptual model based on existing information, mainly from the Netherlands, Davy *et al.* (2006) identified five types of dune slack. The model shows examples of slack types based on two groundwater flow systems; a local circulation of fresh groundwater in the dune system recharged directly by precipitation and a regional groundwater flow system originating in the inland area and discharging in the coastal zone.

The degree of influence of any regional flow system will depend on the extent and nature of the underlying geological unit as to whether it forms an aquifer of good hydraulic conductivity or an aquitard of poor hydraulic conductivity (for example, with layers of clay). Local groundwater flow circulation in the dune system will occur at depth if the sand is free-draining with a shingle base but flow may be restricted by the presence of clay lenses or peat layers.

Dune slacks types as proposed by Davy *et al.* (2006).

- A. Seaward, young dune slack in reach of the transition zone between the circulation of fresh and saline ground-waters and so may be subject to brackish conditions.
- B. Precipitation-fed slack situated in a dune hollow formed by a blow-out. Groundwater flow is directed towards the slack and water is lost by evapotranspiration.
- C. Precipitation-fed flow-through slack. Groundwater flows into the up-gradient edge of the slack, flows through the slack and then exits the slack at the down-gradient edge before continuing to flow in the direction of the hydraulic gradient.
- D. Slack at boundary between the dune system and inland area. Slacks are fed by both the regional and local groundwater flow systems and may also receive some surface run-off.
- E. Moist dune slack situated at a high elevation in the main dune area. Moisture in the capillary fringe above the water table keeps the base of the dune slack moist with only occasional flooding when the water table is high in wet years.

The typology has been prepared by a multi-national (United Kingdom, Netherlands, Germany) research group but would benefit from further field testing (Davy *et al.* 2006).

On large dune systems the water table is usually dome-shaped with the highest point up to several metres higher than the lowest. The water table responds directly to rain-fall with greater seasonal changes in the centre than near the edges. The seaward edge of the aquifer in some situations can be influenced by the tidal cycle. The landward edge however is often influenced by human interference in the hydrology. Especially when dunes are adjacent to polders, hydrological conditions are highly artificial due to agricultural drainage regimes.

The number of plant species in any slack may be correlated to the size of the slack (large slacks hold more species). Slacks, however, have few endemic species; many slack species are also found in calcareous fens and other wetlands. *Carex trinervis* (three-nerved sedge) is probably the only plant species which is largely confined to western European dune slacks (Foley 2005).

In European vegetation classifications, species rich humid dune slacks are placed within the *Caricion davallianae* communities.

Table 1: Main sub-types of humid dune slacks identified in the EUNIS and Corine biotopes classifications

EUNIS	B1.8	CORINE	16.3	EU Interpretation Manual
Moist and wet dune slacks		Humid dune slacks		Humid dune slacks
Dune slack pools	B1.81	Dune slack pools	16.31	Freshwater aquatic communities of permanent dune slack water bodies
Dune slack pioneer swards	B1.82	Dune slack pioneer swards	16.32	Pioneer formations of humid sands and dune pool fringes, on soils with low salinity
Dune slack fens	B1.83	Dune slack fens	16.33	Calcareous and, occasionally, acidic fen communities, often invaded by <i>Salix repens</i> occupying the wettest parts of dune slacks
Dune slack grassland and heaths	B1.84	Dune slack grasslands	16.34	Humid grasslands and rushbeds of dune slacks, also often with creeping willows (<i>Salix rosmarinifolia</i> , <i>S. arenaria</i>)
Dune slack reedbeds, sedgebeds and canebeds	B1.85	Dune slack reedbeds and sedgebeds	16.35	Reedbeds, tall-sedge communities and canebeds of dune slacks
Wet dune slacks: dominated by shrubs or trees	B1.86	No category		

In the United Kingdom five types of humid dune slacks are identified in the National Vegetation Classification (NVC) (Rodwell 2000). Four types (SD13, SD14, SD15 and SD17) are associated with the habitat type 2190 humid dune slacks. The SD16 community (drier slacks) represents the habitat type '2170 dunes with *Salix repens* ssp. *argentea* (*Salicion arenariae*)' (JNCC 2007).

There are broad similarities between these humid dune slack types and the rest of northwest Europe, particularly the more calcareous slacks (Davy *et al.* 2006). Not covered in the UK classification, however, are dune slack pools, the acid types on the Wadden Sea islands, pioneer acid dune slacks and dune slacks with saline influence and older heathland stages of slack development.

A comprehensive overview of vegetation ecology in dune slacks in the Netherlands is given by Aggenbach and Jalink (2001) for decalcified slacks and Aggenbach *et al.* (2002) for calcareous dune slacks. It is also probably applicable for most of the north-western European slacks.

The vegetation of the dune slacks of the Wadden Sea islands has been extensively sampled (Petersen 2000). Dune slack vegetation is represented in the classes *Littorelletea uniflorae*, *Isoeto-Nanojuncetea*, *Saginetea maritimae*, *Scheuchzerio-Caricetea nigrae*, *Calluno-Ulicetea* and *Oxycocco-Sphagneteta*.

In Portugal, humid dune slack communities are also associated with habitat types 3130 oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and /or *Isoeto-Nanojuncetae* and *3170 Mediterranean temporary ponds.

Humid dune slacks also occur in the Mediterranean region. In the Veneto region of Italy, for example, characteristic species of the humid dune slacks are *Juncus articulatus* (jointed rush), *Cyperus flavescens* (yellow galingale), *Samolus valerandi* (brookweed), *Blackstonia perfoliata* (yellow-wort) and *Phragmites australis* (common reed) (Fiorentin 2006). Dune slacks are a rare and threatened habitat in Greece and are a priority for monitoring (Dimopoulos *et al.* 2006).

Vegetation succession in dune slacks, described in literature from the Netherlands and the United Kingdom (see Davy *et al.* 2006) starts with the open conditions of bare wet sand some of which may be affected by salinity and tidal flooding. Microbial mats can be important at the pioneer stage and, by fixing nitrogen, may facilitate colonisation by higher plants. *Salix* spp. (e.g. *Salix repens* creeping willow) usually colonise early in the succession but at this stage do not dominate. A species-rich phase of typical dune slack species (including *Liparis loeselii* (fen orchid), *Dactylorhiza incarnata* (early marsh-orchid) and *Epipactis palustris* (marsh helleborine)) develops, often rapidly.

Without the disturbance of grazing, or damage caused by anaerobic conditions in very wet slacks, the biomass increases, organic matter accumulates and the nutrient status (particularly nitrogen and phosphorus) of the soil increases. This results in increasing dominance of tall grasses and shrubs (including *Calamagrostis epigejos* (wood small-reed) and *Salix repens*) and the decline of the typical slack specialists of the species-rich phase. The shift from pioneer stage to more mature stages usually takes about 20-30 years with *Salix repens* often becoming dominant.

The hydrochemistry of dune slacks is complex and can be affected by, amongst other factors, salinity, the alkalinity of the local and regional groundwater flow systems, seasonal fluctuations, the chemical nature of the parent sand (carbonate content) and the production of plant toxins in anaerobic conditions that result from waterlogging.

Species that depend on the habitat

There are few species which could be considered to be dependent on humid dune slack habitat. *Carex trinervis* is an example for vascular plants. For the invertebrates *Quickella arenaria* (syn. *Catinella arenaria*) is a snail with a disjunctive area, occurring in Western-European dune slacks but also in the Alps. It is included as low risk/near threatened on the global Red List (IUCN, version 1996) (Cucherat and Demuyck 2006).

Important species occurring in dune slacks include *Bufo calamita* (natterjack toad) in northern Europe, *Liparis loeselii*, *Petalophyllum ralfsii* (petalwort) and a number of species of stonewort. Dune slacks, especially seasonally flooded pools within the slacks, are one of the main breeding sites for *Bufo calamita* throughout its range. In the Veneto region of Italy dune slacks are important for a range of amphibians including the priority species **Pelobates fuscus ssp. insubricus*, *Rana dalmatina* and *Bufo viridis*. (Fiorentin 2006)

Dune slacks are important for a range of rare mosses and liverworts, including *Petalophyllum ralfsii* and several species of *Bryum* (thread-mosses). These species thrive mainly where there are bare patches of calcium-rich sand within young slacks. They require fresh surfaces of bare damp sand to aid their colonisation. Once these areas become colonised by larger plants such as *Salix repens* and the bare sand disappears the slacks become less suitable for bryophytes (Holyoak 2003). Where new habitat is not being created naturally by dune dynamics the bryophyte flora is thus threatened by lack of grazing pressure, loss of rabbits and encroaching scrub, especially *Hippophaë rhamnoides* (sea buckthorn).

Liparis loeselii is confined to short swards of rich fens and damp calcareous dune slacks. Studies in south Wales (Jones and Etherington 1992) showed that the orchid occurred most frequently in communities less than 40 years old and that seedling survival was best in young, partially vegetated slacks with some bare soil.

Related habitats

Salix repens is commonly found in dune slack vegetation and the boundaries between humid dune slacks and habitat type 2170 dunes with *Salix repens ssp. argentea* are often difficult to define on the ground. Dunes with *Salix repens* often mark the mature phase of calcareous dune slacks (the SD16 community in the UK National Vegetation Classification).

A range of other wetland types, especially swamp, mire and tall herb fen community, occur within the 'slacks' on some dunes. Although not confined to dunes they comprise an important part of the mosaic. Slacks characterised by a prominence of *Cladium mariscus* (great fen sedge) may be of the habitat type 7210 calcareous fens with *Cladium mariscus* and species of the *Caricion davilliana*.

Dune slack habitats do not always fit to the definition of 2190 humid dune slacks and can range from temporary water bodies to mature wetland communities lying within the larger dune systems.

Ecological services and benefits of the habitat

Large areas of dunes in the Netherlands provide drinking water for local use and to supply the main cities in North and South Holland. The exploitation of the dunes for drinking water began in the mid-nineteenth century. In the 1980s it accounted for 15% of all drinking water in the Netherlands (Koerselman 1992). Dune waterworks supply much of the drinking water needs of The Hague, Amsterdam and Leiden. On the Wadden Sea islands water abstraction is often connected with the increasing demands of tourism.

Trends

Dune slacks are a threatened habitat (European Commission 2007). Conifer plantations, surface drainage (on or adjacent to the dunes) and groundwater abstraction have all resulted in a lowering of the water table and less surface flooding at many sites, although the scale of these impacts in comparison to trends (or cycles) in climate is still controversial (JNCC 2007).

Furthermore, in part due to these impacts, most dunes in northwest Europe have become substantially more stable over the last 50 years, thus new secondary dune slacks are not being created. Loss of grazing pressure also causes accelerated succession to less valuable habitats. Where adverse impacts on the water table still occur, humid dune slack habitat has given way to mesotrophic grassland or scrub woodland. Embryonic dune slacks have disproportionately suffered from these processes, resulting in critically small remaining areas in some dune systems in the United Kingdom (JNCC 2007).

However, there are examples of new primary slack formation on accreting coasts in the United Kingdom (Smith 2007) and on the Wadden Island of Schiermonnikoog (Bakker *et al.* 2005). Smith (2007) describes the formation of a 4km-long strip of saltmarsh, sand dunes, dune slack and swamp communities up to 200m wide which has developed over 20 years on the Sefton Coast, northwest England. The habitats covered 62ha by 2005. A developing dune ridge on the foreshore impeded drainage of freshwater seawards and a series of lagoon features appeared (with both freshwater and marine influences).

Over time the lagoons developed a complex mosaic of dune slack, high-level saltmarsh and swamp communities. The number of plant species recorded has increased progressively from 2 in 1986 to 269 in 2007. The site is rich in species associated with young dune slacks including *Centaureum pulchellum* (lesser centuary), *Centaureum littorale* (seaside centuary), *Sagina nodosa* (knotted pearlwort) and *Trifolium fragiferum* (strawberry clover). As the habitats mature a number of 'classic' slack species such as *Parnassia palustris* and species of marsh-orchids begin to colonise. A further stage in the evolution of the site comes with the survival of *Alnus glutinosa* (alder) seedlings along old strandlines, producing incipient lines of wet woodland (Smith 2007).

A similar feature has been described for Schiermonnikoog (Bakker *et al.* 2005) where a green beach developed in the 1960s. In the 1990s a new dune ridge formed leading to vegetation growth of 200-400m width along a 10 km front. However, the dune slack vegetation is restricted to parts of the beach where low soil salinity is maintained by freshwater seepage from the dunes at the centre of the island.

Threats

Across Europe dune systems continue to be lost to tourism and residential development. Sites often become fragmented by infrastructure and impacted by coast defence works reducing the opportunities for natural processes to create and maintain dune slack habitat. Across their range humid dune slacks are threatened, by loss, physical damage, eutrophication, overgrowth through lack of grazing and interference with natural hydrological processes. Climate change also presents a significant threat to the status of dune water tables.

Water abstraction and drainage

Water abstraction and drainage are the principal threats to dune slacks where the vegetation communities may be sensitive to relatively small fluctuations in the natural seasonal fluctuations. This is especially the case for the lower plants.

Dune slacks are fed by precipitation, surface water and groundwater. The latter two sources are usually calcareous while the former is acid. Groundwater may come from different hydrological systems.

The sensitivity of the slack types identified by Davy *et al.* 2006 is shown below based on five slack types.

Table 2: Sensitivity to abstraction/drainage of the main slack types by Davy *et al.* 2006

Type	Description	Hydrological conditions	Sensitivity to abstraction /drainage
A	Seaward, young dune slack	Potentially subject to brackish conditions	Low sensitivity since likely to be of an ephemeral nature
B	Precipitation-fed slack situated in a dune hollow formed by a blow-out	Groundwater flow directed to the slack with water then lost by evapotranspiration	High sensitivity since affected by water table fluctuations in response to seasonal wet and dry conditions
C	Flow-through slack.	Groundwater flows into the up-gradient edge of the slack, flows through the slack and then infiltrates at the down-gradient edge	High sensitivity as above.
D	Slack at boundary between the dune system and inland area	Water levels buffered by regional and local groundwater flow systems	Moderate sensitivity since slack water levels are maintained by steady regional groundwater flow even during dry weather.
E	Moist dune slack situated at a high elevation in the main dune area		Very high sensitivity since only in reach of moisture in the capillary zone with only occasional flooding.

Abstraction of groundwater in the Doñana National Park in Spain (Muñoz-Reinoso 2001) caused an increase in the spread of scrub and trees (especially *Pinus pinea*) by reducing the frequency of flooding even in areas some distance from the main slacks.

The main concern in the United Kingdom has been the abstraction of groundwater for the irrigation of golf courses. Abstraction licences in Natura 2000 sites are carefully monitored by statutory agencies. The results so far imply that the impacts of abstraction are generally local and thus less significant than drainage schemes which may have consequences over a wider area.

The impacts of abstraction have been particularly acute in the Netherlands where few sites exhibit natural processes compared with the situation in the 1850s. Over-abstraction led to the lowering of the dune water table (by an average of 2-3m) and to salt water infiltration under the dune aquifer. Many of the former slacks were dried out and lost their ecological value. The negative impacts of groundwater abstraction have been ameliorated since the 1950s by using 'infiltration water' drawn from the rivers Rhine and Meuse but wet slack habitats remain affected to some extent. At first the action was equally damaging as it led to the flooding of slacks with nutrient-rich water bringing problems of water quality and the growth of tall nitrophilous marginal vegetation. Plants such as *Parnassia palustris* (grass-of-Parnassus) disappeared. The ecological problems have been well documented (see, for example, Koerselman 1992).

Lack of natural dynamics

The fixation of dunes by planting *Ammophila arenaria*, scrub and trees (for example, in the Netherlands and Denmark) has reduced dune mobility and, as a consequence, the formation of secondary slacks.

Although dune stabilisation and the removal of grazing animals from dune areas at first affects the fixed dunes there is a positive feedback mechanism between increased biomass production and decreased groundwater levels. Tall vegetation types, such as scrub and woodland, intercept more nutrients from atmospheric deposition than open and short vegetation types, leading to increased growth and a higher evapotranspiration. The result is further reduction in water tables during the summer. If the supply of groundwater decreases, shrubs and tall grass species invade the site and pioneer communities are lost to competition. (Stuyfzand 1993 in Davy *et al.* 2006).

Atmospheric nitrogen deposition

Increasing nitrogen deposition may accelerate the accumulation of organic matter in the substrate. The growth of most pioneer species is limited by nitrogen so these will respond to the addition of nitrogen. On the other hand phosphorus limitation may be more important in limiting the growth of tall grasses which are limited by both nitrogen and phosphorus. In the more calcareous slacks there is some buffering if the soil pH remains above 6. In the Wadden Sea islands the pH of slacks ranges from calcareous (mean pH 5.8 -6.8) to acid (mean pH 4.7-5.1) (Petersen 2000).

Phosphorus availability is relatively high in older and acid stages in dune slacks of the Dutch Wadden islands because the soils are poor in iron and here the phosphorus is only loosely bound to iron-organic compounds (Kooijman and Besse 2002). Slacks in the more acid dune areas are thus prone to invasion by tall grass species such as *Calamagrostis epigejos*.

More detail on the recorded levels of nutrient deposition on European dunes is given in the Management Model for fixed dunes (*2130). Most of these record the overall nutrient load affecting the wider dune system. There is less specific information on the impact of nutrient deposition on dune slacks. A study of the impact on nitrogen deposition on United Kingdom dunes (Jones *et al.* 2004) found no clear evidence of change in humid dune slacks (when significant change was detected on fixed dunes) but suggests that N deposition is bound to find its way into groundwater.

Afforestation

Afforestation may have a direct effect on dune slacks if they are targeted for planting (often linked to drainage activity) and an indirect effect by drawing down the overall water table in the vicinity of plantations. Detailed studies at Newborough Warren, Wales have shown that the water interception and transpiration associated with forest is likely to have an adverse influence on groundwater recharge and levels (Betson *et al.* 2002, Bristow 2003 cited in Davy *et al.* 2006). A groundwater model constructed for Newborough Warren showed that potentially removing forest in the topographically high area of the reserve would allow greater recharge that would benefit groundwater levels across the site and so help maintain dune slacks.

Under-grazing

Where grazing levels are too low to prevent the establishment of coarse grasses, scrub and woodland the vegetation communities of the younger, species-rich, slack will be threatened. For example, on the 600 ha Kenfig dune system in south Wales the level of agricultural grazing, with sheep at a stocking density of 0.2/ha, was too low to prevent the expansion of scrub both on dry dunes and in wet slacks (Jones 1996). Under-grazing was linked to problems with scrub development, an increase in coarse grassland, a general increase in the rate at which vegetation types pass into later seral stages, a reduction in bare sand and the displacement of species such as *Liparis loeselii* and *Petalophyllum ralfsii*.

Shoreline management

Few parts of the European coast are unaffected by anthropogenic activity. Sea defences, shoreline management and harbour management activities have limited the opportunities for the spontaneous formation of new primary slack features. In the Netherlands a number of such features, called 'green beaches' have been accommodated within large scale economic developments.

On the Sefton Coast, northwest England modern shoreline management policies, coupled with recreation management policies (Smith 2007) have allowed the development of a significant new area of primary slack habitat. Only some 50 years ago such spontaneous developments would probably have been 'reclaimed' to form new land. The closer inter-linking of the EU Habitats Directive with second-generation Shoreline Management Plans in England and Wales may give new opportunities for the development of primary slacks.

Climate change effects

Climate change could pose a significant threat to the already rare wet slacks habitats. Slacks are habitats dependent on groundwater quantity and quality (EU Water Framework Directive 2000). Any lowering of groundwater levels would leave many of the existing slacks 'high and dry'.

Recent research (Clarke and Sanitwong-Na-Ayutthaya 2007) has used UK Climate Impact Programme (UKCIP) data to model the effect of climate change scenarios on the extensive wet slack system of the Sefton Coast (40% of this habitat type in England). The model is supported by over 40 years of hydrological monitoring data (water table height and rainfall patterns) and gives predictions of more extremes in the fluctuations of the water table and longer periods of droughts. Overall, it is predicted that the dune water table may fall by up to 1m by 2080.

On this system where the dune areas are large or still exhibit dynamics it may be possible to 'chase the water table' by either large scale turf-stripping works or through the re-activation of aeolian dynamics. However, in the stable dunes, which include golf courses and other recreation sites, it would be difficult to envisage such conservation-led projects under current management approaches.

A study of geomorphological changes to Welsh sand dunes under scenarios of rising sea-level (Pye and Saye 2005) showed that this may also impact on the hydrology of the dune systems. Two opposite effects are identified:

- (i) the lowering of the groundwater levels as a result of coastal erosion and narrowing of the dune belt leading to drier conditions and deflation of the dune surface; and
- (ii) rising sea-level causing an increase in groundwater levels.

A rising water table in response to an increase in sea-level may be expected to favour humid dune slack species and to encourage sand stabilisation in low-lying areas (Pye and Saye 2005) although saline water intrusion may cause brackish conditions in coastal slacks near the shore. Rising groundwater levels would, however, not lead to the rejuvenation of existing wet slacks (Noest 1991) as the humus layer which had already developed would need to be removed. Potential increases in summer rainfall may reduce the success of slack restoration projects if the slacks remain flooded in the summer (Grootjans *et al.* 2007)

Further work is required on climate change predictions for humid dune slacks in a number of different scenarios and including their geographical variability.

2. Conservation management

General recommendations

The development of appropriate management prescriptions for dune sites depends on knowledge on a number of issues, including the history of site management, trends in vegetation development, current land use etc. For the management of humid dune slacks it is also important to understand the hydrology of the site. To make the best choices dune managers need to develop a basic understanding of how dune systems and humid dune slacks 'work' and how external factors such as drainage and abstraction may have a major impact on desirable objectives. Readers of this management model should consult the decision-tree for dune management developed with LIFE Nature funding (www.barger.science.ru.nl) and Brouwer *et al.* 2005)

The experience of coastal dune management in Europe has been recorded in a series of conference proceedings sponsored through EUCC-the Coastal Union (including van der Meulen *et al.* 1989, Carter *et al.* 1992, Houston *et al.* 2001, Herrier *et al.* 2005). Case studies are provided on www.coastalguide.org. Coastal dune managers in Europe are also supported by 'dune networks' linked to the Coastal Union-EUCC, for example www.hope.ac.uk/coast .

The most up-to-date review of humid dune slacks, applicable to much of northwest Europe is available from Natural England (Davy *et al.* 2006)

The conservation of humid dune slacks requires either natural hydrological conditions or the careful manipulation of hydrological conditions to mimic the natural fluctuations in water levels which maintain the habitat.

In the natural situation the formation of humid dune slacks will be through geomorphological processes, including the development of active blow-outs. Where such processes are limited it is possible to create the habitat conditions by artificial means. For such interventions to be successful there has to be good knowledge of the hydrological conditions.

The species-rich stage of humid dune slack succession can be prolonged through active recurring management. In the long-term, however, the full expression of humid dune slack types requires active dune systems where new slack habitat can be formed to replace the loss of drier slacks to succession.

Active management

There is considerable experience in the management of humid dune slacks from the maintenance of favourable condition through grazing and mowing regimes to techniques which aim to mimic natural dune dynamics by using bulldozers to take the development of humid dune slack communities back to earlier stages in succession (see for example Grootjans *et al.* 2002 for a review of activity in the Netherlands).

The more intensive management of dune slack vegetation is common practice in countries such as the United Kingdom (Simpson 1998), Netherlands (Grootjans *et al.* 2002), Belgium (Leten *et al.* 2005) and France (Lemoine 2005, Lemoine and Faucon 2005). In a country such as Estonia, on the other hand, the humid dune slack communities are generally left to develop naturally towards more wooded communities (Are Kont, pers. comm.)

The management of humid dune slacks is driven by a number of concerns;

- Amelioration for the lowering of the water-table by human means (e.g. the impact of water abstraction)
- The desire to maintain low, species-rich (often orchid-rich) vegetation of early to middle-aged slacks
- The desire to have some representation of embryo slacks in the mosaic of dune habitats

- The conservation of a range of species (including *Bufo calamita*, *Liparis loeselii* and *Petalophyllum ralfsii*)

Less attention has been given to the value of mature slacks, both dry slacks (often dominated by grasses) and wet scrub and woodlands (principally of *Betula* spp., *Salix* spp. and *Alnus* spp.).

Scrub control

Humid dune slacks are prone to invasion by scrub species from the adjacent dry dune area and also lose species-richness from rank growth of *Salix repens*. At Ainsdale in northwest England a number of restoration techniques were developed to counter the problem of invasion by scrub and rank grasses which took place following the decline of the rabbit population (Simpson 1998).

In the 1970s the removal of *Hippophaë rhamnoides* scrub was started by hand with the help of volunteers. Vegetation monitoring showed that after 10 years a relatively good dune slack flora had been restored. The work was continued using contractors with chainsaws, brush-cutters, Hymacs (tracked vehicles with a long reach arm and bucket) and tractors with specialised rakes and grabs. Bulldozers were also used but care was needed to ensure that soil was not collected along with the cleared scrub. Stumps were treated with herbicide and cut material was burned on site in areas of low conservation value. Ashes were buried under 1m of pure sand or removed to a dump site. Herbicide spraying was required to deal with re-growth in the next season, ideally followed up by grazing. Details of the techniques, including machinery used, time taken and costs are given in the review by Simpson (1998).

Similar restoration work is described for De Westhoek in Flanders (Leten *et al.* 2005), for the Dune Marchand in France (Lemoine 2005) and the Atlantic dunes of France (Gouget and Bertin 2007). In De Westhoek large scale action began in 1997 to restore 6.7 ha of dune slacks by first removing *Ligustrum vulgare* (wild privet) and mixed scrub. A tractor with an improvised flail smashed the scrub to pieces, leaving only scattered *Quercus* and *Crateagus* trees and some *Prunus spinosa* (blackthorn). A caterpillar crane (Hymac) with a toothed shovel was used to rake up the material into heaps for burning on site. The ashes were removed from the site. The soil underneath the fire sites was excavated (the material was used to construct permanent service tracks) to provide drinking pools for the extensive grazing programme.

In subsequent phases of the work (Leten *et al.* 2005) a heavy-duty flail was used mounted on the 7m-arm of a caterpillar tracked vehicle. Despite the size of the equipment there was limited compaction or disturbance of the soil. However, there were problems in removing the fine material which results from flailing. Several techniques were tried. Manual raking was successful but labour intensive and expensive. The solution was to remove a shallow turf layer (less than 5cm) and to use the sods to stabilise access tracks.

Further problems were encountered after 1999 when it became forbidden to use fire as a management tool. The only solution was to remove debris and litter with as little of the topsoil as possible. This was only possible in the more or less flat dune slacks and was considered to be in conflict with the desire to respect soils, micro-topography and relict populations. Where it was too expensive to remove material from sites the debris was either stacked into an artificial 'dune' or chipped for use on reserve paths.

The experience derived from the LIFE Nature projects in Flanders (Leten *et al.* 2005) stresses the need for good preparation and for control and follow-up management. For large-scale restoration projects an access network can be planned and cut at the start of the project and vegetation mapping can be used to set out an 'optimal' mixture of open dunes, slacks and scrub. Follow-up work to control re-growth is essential (mowing, weeding seedlings, herbicides). Species-rich vegetation is developing in almost all 'young' (25-50 years) and 'middle-aged' (50-100 years) wet dune slacks 4-6 years after large-scale scrub removal and restoration of nutrient-poor conditions (Leten *et al.* 2005).

A case study of the management of the Dunes de Merlimont (Dermaux and Veillé 2007) describes the restoration actions for dune slacks threatened by scrub development. Manual cutting is used and low ground pressure vehicles (quads) used to remove material. The project has restored 5 ha of slacks with cost given as €3,500-4,500/ha for restoration and €1,500-2,200/ha for maintenance management.

Mowing

Slacks are probably mown (at least partly) in most European countries. Mowing is a management technique, which when applied without addition of fertiliser prevents grasses, *Salix repens* and tree species from dominating. The production of dead biomass is reduced leading to decreased nutrient cycling and possibly also a shift in the type of nutrient limitation from N-limitation to P-limitation (Koerselman 1992). Mowing, however, does not prevent the accumulation of organic matter in the top soil layer and it does not prevent acidification in decalcified soils. It is most useful for sustaining young calcareous slacks.

Mowing of dune slacks has also been undertaken at Ainsdale, northwest England. Mowing experiments started in the 1980s to counter the increase in height of *Salix repens*. Autumn mowing was introduced, but following a visit to Dutch sites in 1987 *Salix repens* was cut in the spring in the drier areas which reduced its vigour more effectively (Simpson 1998, Simpson *et al.* 2001). Both flail and rotary mowers have been used successfully. Flails tend to produce a cleaner cut, though it is more difficult to rake and collect the chopped material. Rotary chains proved to be more successful than blades which require more maintenance (Simpson *et al.* 2001). All cut material must be removed to avoid a build-up of nutrients and the development of 'thatch', smothering the seed bank. On wet ground tractors with low ground-pressure tyres should be used.

There is a need for further comparison of mowing regimes in different types of slacks with differing conservation objectives. Although spring mowing has been adopted to control *Salix repens* early mowing will prevent seed set.

A mowing regime has been established at Kenfig in south Wales to conserve the populations of *Liparis loeselii*. Mowing is carried out using a tractor and flail mower with heavy-duty hammer flails (Carrington, pers. comm.). Cuttings are collected with a high-lift machine which uses a combination of flail and scarifying blades to throw cuttings into a collection box which is tipped, when full, using hydraulic rams. Collection of cuttings is a slow task compared with the initial cutting, taking 3-4 times as long. Cuttings are usually left on site for several years (biomass pile) to allow them to compress prior to removal. Mowing is already combined with light grazing, and rabbit grazing, and the long-term aim is to manage the slacks by grazing alone.

Mowing is also practised in Belgium (Leten *et al.* 2005) where the problems of scrub invasion were first noticed in the 1970s. Management work initially focused on eco-gardening techniques for rare species. However, in 1995 a wider mowing programme was developed and 10.75 ha of slacks were mown in 2004. The botanical results of mowing are good in general if the abiotic conditions are suitable.

Grazing

Extensive grazing is considered the ideal form of slack management (Simpson 1998, Leten *et al.* 2005, FitzGibbon *et al.* 2005). At Ainsdale, northwest England, after initial removal of dense scrub, hardy breeds of sheep and cattle have proved valuable, particularly Herdwick sheep and Aberdeen Angus and Hereford cattle. Monitoring recorded increased species diversity, reduced height of target species such as *Salix repens* and the development of a low structural mosaic of vegetation types with bare sand patches.

However, an early survey of grazing of British sand dunes (Boorman 1989) suggests that whilst sheep grazing is ideal in damp slacks the breeds are susceptible to foot problems in wetter areas. Here either grazing with cattle or horses or mowing would be the better solution. Boorman also notes that the higher productivity of dune slack communities should allow grazing at higher densities than on fixed dunes.

Extensive grazing is applied at Newborough Warren in north Wales. The aim is to replicate a 'natural' grazing system. Conservation grazing often relies on the skills, knowledge and expertise of farmers, who typically use a single species of livestock seasonally and at a set stocking density (Sandison 2005). The Countryside Council for Wales manages a herd of feral Welsh mountain ponies on dune habitat (fixed dunes and slacks) based on four guiding principles:

- All year grazing
- A variety of herbivore types: small, medium, large (ruminants and ungulates)

- Multi-sex and multi-age herbivores
- Attention to animal welfare requirements

A herd of 160 ponies grazes the 650 ha reserve, at a stocking density of about one pony to every 3-4 ha. The grazing creates a short sward during the winter/spring period and allows a profusion of growth during the summer. The site also supports an increasing number of rabbits. The site managers are considering the introduction of sheep to fill the medium-sized niche. Details of the establishment of the grazing, the public reaction to livestock, the need to remove aggressive stallions, animal welfare issues and EU legislation are given by Sandison (2005).

The experience of conservation management for dune slacks in Flanders (Leten *et al.* 2005) shows how characteristic species such as *Parnassia palustris* can be encouraged by the combination of scrub and litter removal followed by either mowing or extensive grazing.

The results of a seven-year (1997-2003) grazing trial at Branton Burrows, southwest England (FitzGibbon *et al.* 2005) showed that a mixed grazing regime (cattle and sheep) had a beneficial effect on the plant community, in terms of an overall increase in species richness, control of some scrub species and an increase in typical sand dune species. However, the study found that grazing had little impact on the cover of *Salix repens*.

The scrub management handbook (FACT 2003) offers advice on livestock breeds best suited to control of scrub and coarse vegetation. Such breeds used at Branton Burrows include Devon Red cattle, and Portland, Soay and Herdwick sheep.

Humid dune slacks provide excellent grazing material for rabbit populations. Warrens are often found near slacks or on high 'islands' within slacks. At Kenfig in south Wales rabbits are encouraged by digging artificial holes and by mowing access strips from warrens to slacks (Carrington, pers. comm.).

Sod –cutting

Present-day sod-cutting has proved to be an effective technique if the objective is to restore the slack to an earlier stage of succession. The sod-cutting itself can reveal the history of slack development from the pioneer stage to the mature stage so it may be useful to analyse a test excavation.

Such studies (described in Davy *et al.* 2006) have shown that for the first 10 years organic matter is stored in the living plants, particularly in the root system. After about 15 years the amount of soil organic matter increased and a thick (c. 10 cm) organic layer developed.

Some pioneer species, such as *Centaureum pulchellum* and several *Juncus* species have long-term persistent seed banks (compared to e.g. *Salix repens*). Such species will respond well to sod-cutting, even if the original pioneer vegetation had disappeared several decades previously. However, not enough is yet known about the survival of many typical dune slack species to be confident that a full community will return following sod-cutting.

Sod-cutting includes the removal of the black organic A-horizon leaving the mineral C-horizon intact. This type of management, carried out by hand, is traditional in many countries in northwest Europe. Sod-cutting (cutting of plaggen) has a long history in the Wadden Sea region as a source of fuel and as a soil improver. Now it is carried out mechanically for conservation purposes and often involves removing some of the mineral subsoil. During World War II slacks on the Wadden islands were turf-stripped (perhaps to cover military installations). The activity did help to return much of the slack series back to a pioneer stage.

Sod-cutting has been used in the restoration of dune slacks in north France (Lemoine 2005). Small-scale test plots (4m²) showed good recovery of characteristic species including *Agrostis stolonifera*, *Blackstonia perfoliata*, *Centaureum littorale*, *Carex viridula* var. *pulchella* and *Sagina nodosa*. A programme of mechanical excavation followed, removing at least 10 cm of the A-horizon.

Re-wetting

There are some examples where water tables are being raised in dune areas to compensate for past drainage or abstraction. A large-scale restoration project has been completed in the Amsterdam Waterworks Dunes to infill one of the drainage canals and raise water levels in the surrounding series of wet slacks over an area of 24 ha (Geelen *et al.* 1995). Studies were initiated in 1989 to model the situation and develop objectives, leading to large-scale engineering works in 1994 to infill the canal, thus raising water levels by up to 2m.

The aims of the restoration project were:

- To create a dune ecosystem which can develop as naturally as possible, with special regard to an undisturbed groundwater system and with opportunities for geomorphological processes
- To offer more opportunities for native and threatened species, namely species of moist and nutrient poor dune slacks and pioneer vegetation
- To restore the natural beauty of the dune landscape

Modelling was essential to get the levels of the to-be-formed slacks right. Too low and they would be flooded, too high and they would be dry. The project also included the reactivation of two parabolic dunes to trigger the natural development of new slack features. This also allows nature to give the final landform. The work was undertaken in four phases:

- Removal of fish from the canal
- Removal of vegetation, mainly *Hippophaë rhamnoides* scrub
- Infilling of the canal with 270,000 m³ of sand previously excavated during construction
- Replacement of white dune sand

Care was taken to ensure that material was deposited in layers; roots first, then topsoil, then a layer of mud from the canal (all below the future groundwater level) and finally the clean, fresh sand. A project of this nature and scale required careful planning and good public relations (Geelen 2001).

Restoration and creation of dune slacks

There may be opportunities for the creation of new slack features, for example, as compensatory habitat under the EU Habitats Directive in coastal works. Sand extraction to reinforce coastal defences, for example, could be designed in a way which creates 'slack' features. Slack features may result also 'by accident'.

As part of the large-scale restoration of the dunes of the Albufera Devesa of Valencia expert-led modelling was used to recreate the natural mosaic of dunes and slacks (malladas) which existed before its destruction in the 1970s for a planned, but never completed, tourism development (Sánchez *et al.* 2007)

Studies in the Netherlands (Grootjans *et al.* 2002) found that the creation of new slacks was not very successful for maintaining populations of endangered species since projects were often carried out in areas where seed banks were depleted, while hydrological conditions and seed dispersal mechanisms were sub-optimal. A conceptual model of the occurrence of endangered Red List dune slack species after restoration measures has been developed by reviewing the success of restoration projects (Grootjans *et al.* 2002).

Four levels of success were identified:

- 1. Unsuccessful projects where measures were carried out in unsuitable sites and where there was no seed bank. Most of these projects were carried out to compensate for losses in existing nature reserves.
- 2. Temporary success, followed by a rapid decrease in typical dune slack species where the soil conditions and hydrological regimes are sub-optimal but where there is still a seed bank. Examples

are freshwater slacks surrounded by decalcified dune areas, where many changes in the hydrological regime had occurred.

- **3. Successful**, but short-lived, reconstruction of pioneer vegetation with many Red List species. Dispersal mechanisms are effective, but environmental conditions are sub-optimal. Mowing may sometimes retard a rapid spread of later successional species and a decline in Red List species.
- **4. Very successful** projects where many dune slack species establish in large numbers and persist for many decades. Natural processes retard the succession towards late successional stages. A mowing regime may stabilise the pioneer stage even longer. Examples include the large sandy beaches on the Wadden Sea islands that were enclosed by artificial dikes or drift sand. Local and regional species pools were available and dispersal mechanisms were still effective. There are also such successful projects in the calcareous dune areas of the Dutch mainland coast.

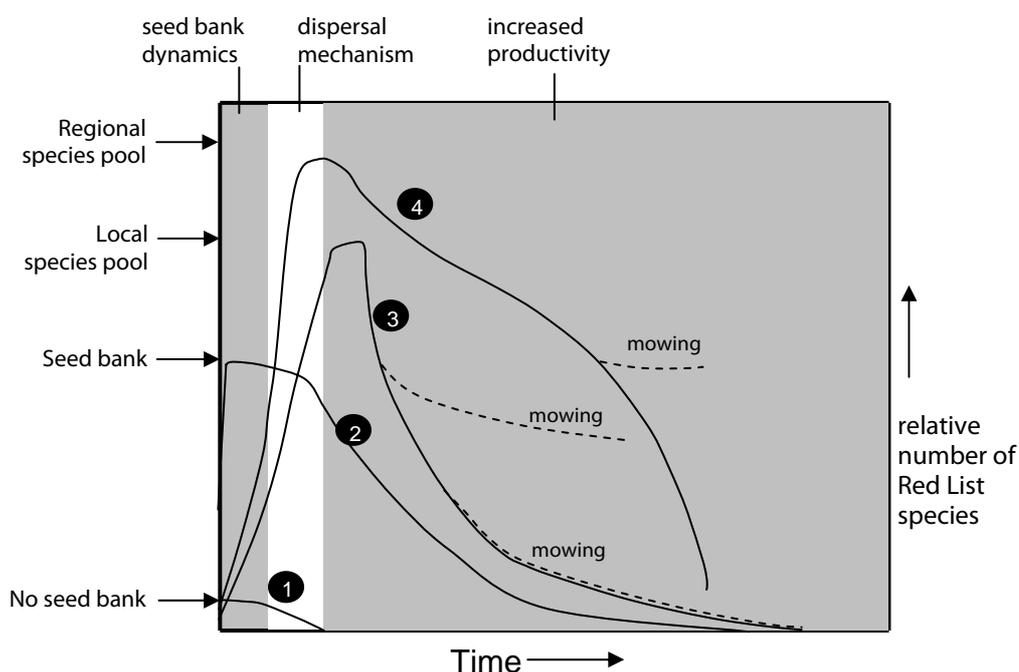


Figure 1. Level of success in the creation of new slacks based on the occurrence of Red List species, after Grootjans *et al.* 2002

The experience of management work in north France (Lemoine 2005) adds to the debate between the values of 'eco-gardening' for maintaining habitat condition and larger scale disturbances to dune systems to reactivate sand drift and allow new landforms to develop. At least in the short-term slack vegetation would appear to benefit from such disturbances. In the Netherlands experiments have sought to reactivate parabolic blowouts (Terlouw and Slings 2005) by, for example, removing topsoil from 30 ha of dunes in the National Park Zuid-Kennemerland.

Other relevant measures

Research and monitoring

Dune slacks are complex habitats. They are well studied in the Netherlands from where most of the scientific understanding has come. In a review of the situation in the United Kingdom (Davy *et al.* 2006) the following monitoring schemes are proposed:

- Further work on the development of the conceptual model of slack typology
- Establishment of field sites for long-term collection of hydro-meteorological and hydro-geological data

- Hydro-chemical sampling
- Autecological study of *Petalophyllum ralfsii*
- Further studies on *Liparis loeselii* var. *ovata*
- Experimental studies into restoration of vegetation communities and eco-hydrological function

For slacks there is a need for ecological studies to be closely associated with hydrological and hydro-chemical studies to gain a good understanding of how humid dune slacks work.

Special requirements driven by relevant species

Bufo calamita (natterjack toad)

Conservation action in dune slacks in the United Kingdom has, at several sites, been driven by the special requirements of *Bufo calamita*. On the Sefton Coast, northwest England a prolonged period of drought in the mid-1970s led to a number of 'emergency' actions to create a chain of breeding pools within the basins of the dune slacks. At Ainsdale about 20 'scrapes' were created ranging in size from 100-5000 m² with an average of 1000m². Large tracked excavators were used to create a range of ephemeral pools favoured by *Bufo calamita* (Simpson 1998). Care was taken to avoid the most important botanical areas.

The newly-created scrape edges were colonised by pioneer species such as *Samolus valerandi* (brookweed). Over time more mature slack vegetation developed including *Dactylorhiza* spp. (marsh orchids), *Carex serotina* (small-fruited yellow sedge), *Anagallis tenella* (bog pimpernel) and *Parnassia palustris*. A number of the scrapes, however, were too deep and remained as permanent ponds attracting predators of *Bufo calamita*. In the 1990s about 10 of the original scrapes were re-profiled to give a flatter surface with no permanent pool. Monitoring of the water table and knowledge of the vegetation communities surrounding each pond was used to calculate re-profiling levels. Clean sand was used to form a base of the re-profiled slacks and excavated material buried under 1m of sand. The work encouraged the colonisation of a number of rare species and some localised sand blow helped to give the restoration work a more natural look (Simpson 1998).

The lesson from this project was that the over-deepening of ephemeral dune pools (undertaken as part of an 'emergency' action) could be rectified with more knowledge and careful works to reinvigorate the natural succession of dune slacks.

The species is also rare in Denmark, with only three viable populations along the Danish west coast (Briggs and Adrados 2005). Habitat restoration work has been successful in extending the populations and recommendations are made for a conservation strategy from 2006-2025. Restoration actions have targeted both the terrestrial and aquatic habitats with scraping of dune slacks, digging new ponds, cutting back vegetation, grazing, mowing and burning of terrestrial habitat.

Bufo calamita can exploit lagoon and young slack conditions where it retains a competitive advantage over other species. At one of the main sites in northwest England tidal inundation of a 'green beach' feature tends to occur at the spring equinox, eliminating the competitive *Bufo bufo* (common toad) tadpoles before *Bufo calamita* spawns. The warm, shallow lagoons and slacks at this site, fed by freshwater drains are perfect for rapid tadpole development (Smith 2007).

Liparis loeselii (fen orchid)

The form *Liparis loeselii* var. *ovata* is confined to early or mid-successional dune slacks in the United Kingdom (the SD14 *Salix repens* –*Campylium stellatum* community). In these slacks the water table regularly falls to more than 0.5m below ground level in August and September. A mowing regime has been established at the Kenfig National Nature Reserve in south Wales to maintain the short turf habitat. *Liparis loeselii* is found in dune slacks in France. Scrub control actions targeted for the conservation of *Spiranthes aestivalis* led to the reappearance of *Liparis loeselii* in the slacks (Gouget and Bertin 2007). Experimental plots have been established in the Gâvres-Quiberon dunes (Elouard *et al.* 2007) to develop a restoration programme for *Liparis loeselii* through cutting and disturbance to the ground layer.

Rare mosses

A number of rare bryophytes are associated with the younger stages of coastal dune slacks in northwest Europe. Their ability to exploit bare sand and young slack habitats is shown in the development of a 'green beach' feature in northwest England (Smith 2007). At this one site in the United Kingdom the 'spectacular abundance' of *Bryum warneum* exceeds the combined total population from all other sites in England and Wales by several orders of magnitude (Smith 2007).

Plantlife International has published a guidance note on looking after rare mosses and liverworts in coastal dune slacks (Holyoak 2003). The management advice is:

- Open habitats are best –aim to keep the dune system as dynamic as possible so that new slacks can be formed
- Light trampling is important for maintaining the open conditions needed by these species. *Petalophyllum ralfsii* positively benefits from trampling, especially where wide diffuse pathways grade from a rather bare centre to short rabbit-grazed vegetation at the edges. Avoid placing boardwalks or diverting paths in areas where these species are known to occur
- Grazing is important to maintain open areas. Rabbit grazing should be encouraged and some patches of scrub can be left to provide cover. Alternatively grazing stock could be introduced. Care needs to be taken with cattle grazing to avoid poaching of the ground around pools in slacks.
- Care needs to be taken when erecting fencing (for visitor control or grazing control) to ensure that preservatives in the wood do not contaminate the ground. Galvanised wires can cause zinc run-off which is thought to be toxic to some bryophytes.
- Drainage will affect the dune system as a whole, not just the immediate vicinity. In slacks affected by drainage or draw-down of the water table efforts to maintain conditions by scraping down to the water-table have met with some success.
- These species are affected by nutrient enrichment which promotes vegetation growth and increasing shade. Local sources of pollution (for example from dog-fouling) can have a significant impact on the bryophyte communities.

Cost estimates and potential sources of EU financing

Specific cost features for the habitat

To our knowledge there are no funding schemes which specifically target the conservation of humid dune slacks. The management of dune slacks would usually be a component of wider management actions for dune systems, such as grazing, mowing or scrub cutting. Actions to target the restoration of humid dune slack habitats could be eligible for agri-environment funding if they are followed by sustained management practice such as grazing.

The management costs for humid dune slacks will vary depending on the objective for management;

- Recurring management of the whole site by grazing (e.g. Sandison 2005)
- Mowing or grazing activity targeted at humid slacks (e.g. Simpson 1998)
- Scrub cutting and small disturbance to maintain open habitats
- Repeated turf-stripping activity to retain young habitats
- Infrequent, but large scale, restoration projects

Member States have opportunities to develop targeted management schemes for habitats and species. In Scotland, for example, the Natural Care programme has developed a conservation scheme for the management of dune, machair and dune slacks at two sites on the islands of Shetland. The aim of the scheme is to provide financial support to land managers to help maintain and improve the conservation value of the sites and to maintain natural processes. The scheme is based on achieving targets for favourable condition without prescribing the actual grazing pattern or number of livestock: local knowledge and experience is considered to be important. The five year management prescriptions also include payments to control rabbit numbers and invasive weeds.

Payment rates are £85/ha (ca. €120/ha) for grazing management, 90% of the costs of rabbit control up to a maximum of £100/ha (ca. €140/ha) and £200/ha (ca. €285/ha) for initial weed control (with follow up treatment at £50/ha (ca. €70/ha)). One-off payments are given for writing the management plan and for rabbit-proof fencing and gates and traps. Rabbit numbers are a problem on these grasslands and the Natural Care scheme can make additional payments over and above the land owners duty to control rabbit as part of cross-compliance with General Environmental and Agricultural Condition (GAEC).

A case study of conservation management on the Dunes de Merlimont (Dermaux and Viellé 2007) gives details of the costs of establishing grazing systems, restoration and management of dune grassland, humid dune slacks and fixed dunes.

Relations with potential sources of EU funds

Management measures for Natura 2000 were defined in the annexes of Communication from the Commission on Financing Natura 2000 (COM 2004-0431 and its working documents). Concerning potential sources of EU financing, a Guidance Handbook (Torkler 2007) presents the EU funding options for Natura 2000 sites in the period 2007-2013 that are, in principle, available at the national and regional level.

Furthermore an IT-tool is available on the EC web site:

http://ec.europa.eu/environment/nature/natura2000/financing/index_en.htm.

Among the diversity of sources for EU funding, the following funds might primarily be of interest for the management of 2190:

- The European Fund for Rural Development (EARDF): This program has a potential to cover several management activities that might be relevant, although the measures have to be covered in the National Strategy Plans and related measures Rural Development plans (RDPs) in order to be eligible on a national basis. Furthermore Leader+ projects have to be studies on a national basis.
- The European Regional Development Fund (ERDF), The Cohesion Fund and Interreg: These funds might be relevant in single cases although activities related to Natura 2000 sites mostly need to be integrated in a broader development context. However, the Interreg approach is more flexible but needs a European objective and partnership. Different geographical levels were defined and all of them have their specific rules, eligibility criteria and objectives.
- The Financial Instrument for the Environment (LIFE+): The 'Nature' component of LIFE+ supports best practice and demonstration projects contributing to the implementation of the Birds and Habitats Directives but only exceptionally outside Natura 2000 sites. The 'Biodiversity' component is for demonstration and innovation projects contributing to the objectives of the Commission Communication 'Halting the loss of biodiversity by 2010 – and beyond'. Both the 'Nature' and 'Biodiversity' components focus on concrete non-recurring management actions (at least 25 % of the budget). Recurring management is not eligible under LIFE+.

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