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MANAGEMENT of Natura 2000 habitats
* Fixed coastal dunes with herbaceous vegetation ("grey dunes")
2130

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The European Commission (DG ENV B2) commissioned the Management of Natura 2000 habitats. 2130 *Fixed coastal dunes with herbaceous vegetation ('grey dunes')

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Calcareous fixed dunes on Sefton Coast, northwest England. Photo: John Houston

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

EUNIS Classification:
B1.4 - Coastal stable dune grassland (grey dunes)

* Priority habitat

Summary

Fixed and semi-fixed dunes occupy a zone between the mobile dunes and the dune scrub and woodland habitats of coastal dune systems. The habitat is a main component of the extensive dune systems along the exposed Atlantic coasts of Portugal and France and also from north France to Denmark and much of the southern Baltic Sea. Grey dunes are found in almost all dune systems in the Atlantic region.

The open nature of the habitat is maintained by extensive grazing, by native herbivores, rabbits and domestic livestock. The grazing of fixed dunes has a long history in northwest Europe but overgrazing, particularly in the Middle Ages, led to widespread sand-drift in many areas.

The threats to the habitat come from over-stabilisation (through techniques to prevent sand-drift), a lack of appropriate grazing levels, growth of native and non-native (introduced) scrub, afforestation and alien species. The most significant concern across the range of sites is the impact of atmospheric nutrient deposition. This is most acute on the more acid sites from the Netherlands eastwards.

The options for managing fixed dune habitats are guided by type. Some dunes are ‘stable’ (and perhaps have been for many decades or centuries) and sustained levels of management are required to maintain dune grasslands, whereas others are ‘dynamic’ and can maintain an equilibrium between cyclical mobility and stability.

Recurring management activity includes grazing (with considerable experience across Europe), burning, mowing, sod-cutting and scrub cutting. In all these activities the aim is to reduce nutrient levels to maintain high numbers of species. In terms of restoration work the most significant activity, reported from several countries, is the removal of conifer plantations to restore open dune conditions.

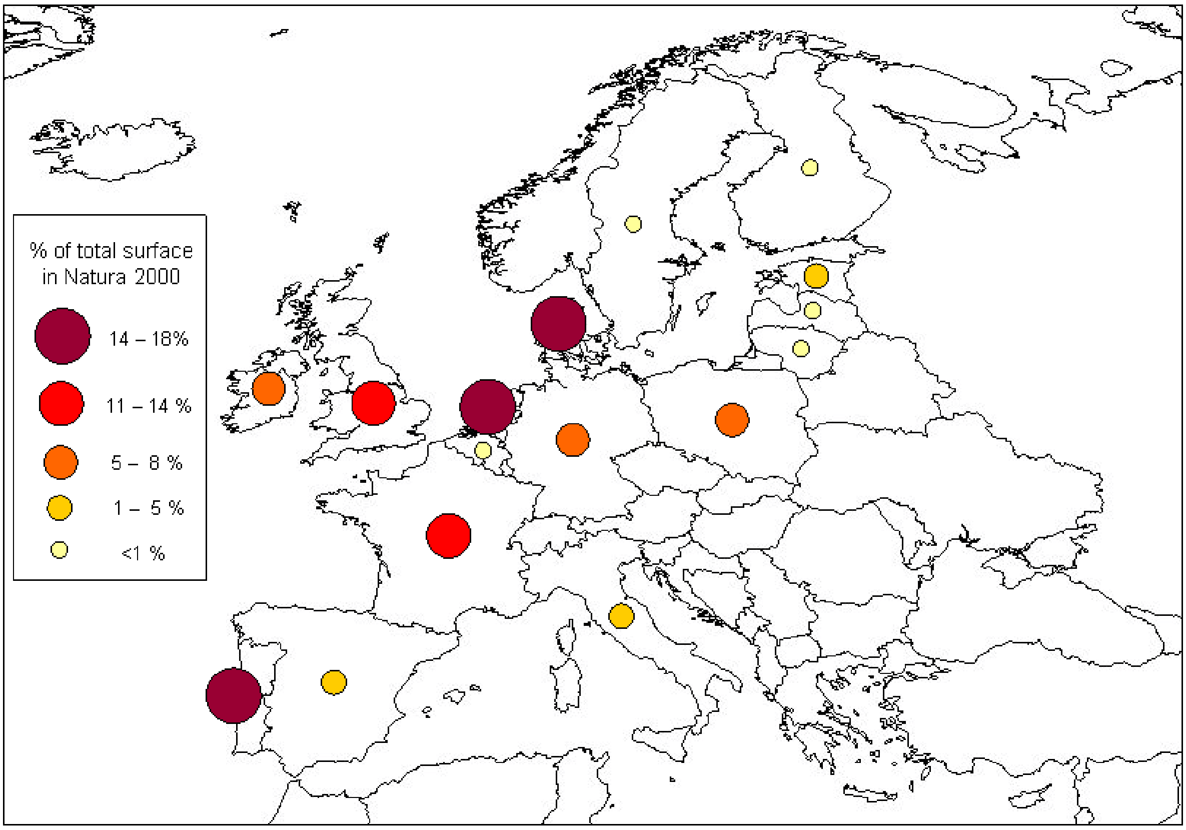
Although the habitat is described as ‘fixed’ in many cases its conservation depends on it being part of the dynamic processes that operate in dune systems. In countering the problems of high nutrient levels the reworking of sand, either through cultivation or through encouraging sand-drift, may ultimately help to conserve the habitat in the ‘dynamic’ dune type.

1. Description of habitat and related species

Fixed and semi-fixed dunes stabilised and colonised by more or less closed perennial grasslands and abundant carpets of lichens and mosses, from the Atlantic coasts between the Straits of Gibraltar and Cap Blanc Nez, and the shores of the North Sea and the Baltic. Similar dunes occur along the coasts of the Black Sea (European Commission 2007)

Distribution

The largest dune areas in Europe are found along the exposed west and north coasts of Denmark (Jutland), the Netherlands, the Wadden Islands, France (Aquitaine) and Portugal. In eastern Denmark and along the Baltic coasts, in the United Kingdom and Ireland, along the Spanish Atlantic coasts and the Mediterranean region dune systems are frequent but do not form a continuous dune coastline. Large systems are also found along parts of the southern Baltic coast in Germany (the Darß -Western Pomerania), Poland (Słowiński dunes) and Lithuania (the Curonian spit). Extensive dune systems are also found along the Black Sea coast (Doody 1991).



Percentage distribution of the total surface of grey dunes in Natura 2000

Fixed coastal dunes with herbaceous vegetation (grey dunes) 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	Nº of sites	Estimated surface in Natura 2000 (ha)	% of total surface in Natura 2000
Atlantic	208	53,866	63.0
Continental	106	15,001	17.5
Mediterranean	21	13,129	15.4
Boreal	56	2,841	3.3
Macaronesian	13	665	0.8
Countries	Nº of sites	Estimated surface in Natura 2000 (ha)	% of total surface in Natura 200
Netherlands	20	15,224	17.81
Denmark	48	12,277	13.96
Portugal	13	12,142	14.36
France	62	11,940	14.20
United Kingdom	30	9,587	11.21
Ireland	43	6,841	8.00
Poland	6	4,623	5.41
Germany	38	4,384	5.13
Spain	51	3,629	4.24
Estonia	21	1,200	1.41
Italy	21	940	1.10
Belgium	1	785	0.92
Lithuania	1	750	0.88
Sweden	25	545	0.64
Latvia	11	321	0.38
Finland	13	314	0.37
TOTAL	**404**	**85,502**	**100**

Main habitat features, ecology and variability

Fixed and semi-fixed dunes (grey dunes) are principally found along the Atlantic coast from the Straits of Gibraltar to the North Sea coasts and the Baltic Sea (European Commission 2007). However, as the thermophilous dune sub-type *Crucianellion maritimae* is also included in the description, a fixed dune type more associated with the Mediterranean, Adriatic and Ionian coasts, examples of the habitat have been identified across a wider geographical area as shown in the table above.

It is important to include semi-fixed dunes in the habitat description. The younger stages in succession are more dynamic with higher species diversity (Isermann, pers. comm.). The habitat generally lies between the mobile element of the dune system and the scrub and woodland of later succession.

Fixed and semi-fixed dunes are generally stable and colonised, at first, by herbaceous rich and, in later successional stages, by more or less closed perennial grasslands and abundant carpets of lichens and mosses. The content of lime (Ca^{2+}) may vary greatly, generally diminishing with age and succession (Salisbury 1925).

Fixed dunes develop as part of a succession from mobile dunes; the decaying tussocks of *Ammophila arenaria* (marram grass), *Calamophila* x *baltica* (hybrid marram) and *Leymus arenarius* (lyme-grass) provide a substantial source of nitrogen in the early stages of grey dune development (Provoost *et al.* 2004, Isermann, pers.comm.).

Fixed dunes are harsh environments which favour xerophytic (drought tolerant) plants and thermophilous (heat loving) invertebrates. Studies in De Westhoek dunes, Belgium, found grey dune surfaces can heat up to more than 60°C and the sand can dry out down to 20 cm deep (Provoost *et al.* 2004). Drought stress can be increased by water repellence, especially in moss-covered dunes (Provoost *et al.* 2004). But, on the other hand a closed moss-carpet can reduce water loss by evapotranspiration compared to bare sand (Isermann, pers.comm.). Soil humidity is a main determining factor in germination and seedling establishment, biomass production, and soil development. Groundwater exceeding a depth of about 2 m under the soil surface is not accessible to most grassland plants (Provoost *et al.* 2004).

The organic matter content, calcium content and sand-grain size are the main factors determining the capacity of the sand to retain water and these factors vary considerably across Europe. Where dune systems overlie shingle formations these are referred to as 'dry core systems' where the rate of leaching is more rapid and acidic conditions can develop close to the foredunes (Rhind *et al*. 2006). Acidic conditions may also be near the foredunes on eroding coasts, reflected in the grain size composition of the sand and the composition of vegetation (Isermann, pers. comm.).

Soil development is countered by several processes. In young moss-dunes physical humus erosion can be considerable, but in more stable grassland the main losses of soil organic matter are due to biochemical decomposition.

Stabilised dune soils decalcify due to continuous carbonate leaching. The process can be slowed by the mobilisation of calcareous sand, from sand sheets, blowouts and 'sand spray' (the light 'rain' of sand characteristic of dunes on exposed coasts) (Provoost *et al.* 2004). Nitrogen and phosphorus are key elements and partly co-limiting in the nutrient dynamics of grey dunes (Kooijman *et al.* 1998). Nitrogen is mainly supplied by the decomposition of plant residues. This partly explains why grass encroachment, probably stimulated by atmospheric deposition of nitrogen, is, once established, self-maintaining due to increased nitrogen mineralization. Moreover soil below *Hippophaë rhamnoides* (sea buckthorn) contains high amounts of nitrogen due to nitrogen fixing bacteria (Pearson and Rogers 1962, Isermann *et al.* 2007).

Fixed dune landscapes are usually characterised by undulating dune forms giving many variations on aspect, slope and micro-climate. On most sites there will be differences in the plant communities on north and south facing slopes, some species being generally confined to specific zones, for example *Corynephorus canescens* (grey hair-grass) on south slopes and *Empetrum nigrum* (crowberry) and *Polypodium vulgare* (common polypody) on north slopes.

Characteristic vascular plants include *Aira praecox* and *A. caryophyllea, Anacamptis pyramidalis, Bromus hordeaceus, Carex arenaria, Cerastium* spp*., Corynephorus canescens, Erodium glutinosum, Erodium lebelii, Galium verum, Gentiana campestris, Gentiana cruciata, Koeleria* spp., *Milium scabrum, Myosotis ramosissima, Ononis repens, Phleum arenarium, Polygala vulgaris* var. *dunensis, Silene conica, Silene otites, Trifolium scabrum, Tuberaria guttata, Viola curtisii,* and *Viola rupestris* var. *arenaria.* The mosses *Tortula ruraliformis, Racomitrium canescens, Polytrichum juniperium and P. piliferum* and lichens of *Cladonia* spp. are also characteristic (European Commission 2007).

Descriptions of the geomorphology and ecology of dunes have been described in textbooks (e.g. Ranwell 1972) and in summaries of national studies (e.g. Provoost *et al.* 2004). The comprehensive paper by Provoost *et al.* (2004) covers all aspects of the ecology, management and monitoring of grey dunes in Flanders and is relevant to much of north west Europe.

Variability

Fixed dunes are an extremely complex habitat type (JNCC 2007). A review of European dune and shoreline vegetation was published by the Council for Europe in 1985 (Géhu 1985). For France Géhu (1985) showed five distinct fixed dune communities. This pattern is repeated across Europe: fixed dune habitat is the most variable aspect of dune systems. Nevertheless similar management issues can be identified.

<u>Northern fixed grey dunes</u>

The grey dunes of the Baltic and North Sea coasts tend to be lime-poor with extensive areas of dune heath (2140) and *Corynephorus* grassland (2130). The change from lime-poor to lime-rich further south lies along the mainland coast of the Netherlands (at around Bergen aan Zee) (Dijkema and Wolff 1983).

Along the Baltic from Germany eastwards continental species like *Artemisia campestris* ssp. *sericea*, *Helichrysum arenarium* and *Festuca polesica* become more important, because of the change from more Atlantic to a more continental macroclimate (Isermann, pers. comm.). Characteristic species (example from Latvia) include *Koeleria glauca*, *Carex arenaria*, *Thymus serpyllum*, *Pulsatilla pratensis*, *Racomitrium canescens*, *Tortula ruralis*, *Alyssum gmelinii*, *Dianthus arenarius* and *Silene borysthenica*.

In the Nordic countries two types (including one sub-type) are identified (Påhlsson 1998):

- Stabilized sand dune of grey hair-grass type: occurs in Denmark and along the coasts of southern Sweden. Typical species are *Aira praecox, Corynephorus canescens* and some lichens including *Cornicularia aculeata* and *Cladonia* spp. On more humid soil *Festuca ovina* agg. may take over. A special sub-type of *Corynephorus canescens* and *Koeleria glauca* is recognized on sandy soils in southernmost Sweden (Skåne County) and Öland and Gotland islands.

- *Festuca rubra* heath type on sand: This rare type is found on soils with slight lime content on Jutland, southernmost Sweden and on Åland Islands of Finland, with *Festuca rubra* and *Hieracium umbellatum* as important elements.

In Denmark grey dunes are calcium poor, because of the low calcium content of the original sea sand, and a more rapid succession to acidified, lichen-dominated habitats which require a certain level of continuous disturbance to maintain a competitive edge over mosses and vascular plants. In younger succession stages *Corynephorus canescens* is characteristic, later dominant plants are often *Carex arenaria* (sand sedge) and *Deschampsia flexuosa* (wavy hair-grass) .

Biscay grey dunes (*Euphorbio-Helichrysion stoechadis*)

Fixed dune grassland on stabilised humus soil infiltrated by dwarf bushes, with *Helichrysum stoechas*, *Artemisia campestris* and *Ephedra distachyia*. This is the main type found in France (Favennec 2007). In Aquitaine it is characterised by *Helichysum stoechas* and *Corynephorus canescens,* and in Vendee by *Ephedra distachyia* and *Rosa pimpinellifolia.*

Thermo-Atlantic grey dunes (*Crucianellion maritimae*)

Suffructescent (herbaceous with woody persistent stem base) communities on more or less stabilised soils low in humus of the thermo-Atlantic coasts of Portugal and south-west Spain with *Crucianella maritima* and *Pancratium maritimum*. In Spain fixed dunes are described for the northern coast and on the south Atlantic-facing coast, especially the Coto Doñana. Typical species include *Crucianella maritima, Helichrysum stoechas, Koeleria glauca, Sporobolus arenarius* and *Carex arenaria.*

Atlantic dune (Mesobromion) grasslands

Characterised by dry, calcicolous grasslands, poor in nitrogen. They include species characteristic of inland dry calcareous grasslands together with maritime species that result from the aerial deposition of salt.

This is the main type found in the United Kingdom (Rodwell 2000). Atlantic dune grassland, consists of a short sward characterised by *Festuca rubra* (red fescue) and *Galium verum* (lady's bedstraw) and is typically rich in species of calcareous substrates. The vegetation shows considerable variation within the United Kingdom. In northern Scotland, *Primula scotica* (Scottish primrose) can occur in this community; in the south, several orchid species are found, including *Anacamptis pyramidalis*, (pyramidal orchid) and a rich variety of other species. In southwest England and in Wales *Thymus polytrichus* (wild thyme) often dominates this type of vegetation. A taller type of dune grassland vegetation, in which *Geranium sanguineum* (bloody crane's-bill) is prominent, is particularly characteristic of north-east England. In areas with a drier and more continental climate, such as Norfolk, and where the substrate is at the acidic end of the spectrum, the fixed dune vegetation is rich in lichens (JNCC 2007).

Atlantic dune thermophile fringes

Geranium sanguineum formations on neutral to basic soils rich in calcium and poor in nitrogen. Characteristic of the grey dune systems of the British Isles and Brittany.

Dune fine-grass annual communities

Sparse pioneer formations of fine grasses rich in spring-blooming therophytes characteristic of oligotrophic soils (nitrogen poor sand or very superficial soils).

Table 1: Main sub-types of fixed (grey) dune identified in the EUNIS and Corine biotopes classifications

EUNIS	**B1.4**	**Corine biotopes**	**16.22**	**Corine sub-types**
Coastal stable dune grassland (grey dunes)		Grey dunes		
Northern fixed grey dunes	B1.41	Northern Atlantic grey dunes	16.221	16.2211 Crested-hair-grass dune communities 16.2212 Grey-hair-grass dune communities 16.2213 Mouse-ear dune communities
Biscay fixed grey dunes	B1.42	Biscay grey dunes	16.222	
Mediterraneo-Atlantic fixed grey dunes	B1.43	Ibero-Mediterranean grey dunes	16.223	
East Mediterranean fixed grey dunes	B1.44	East Mediterranean fixed dunes	16.224	
Atlantic dune [Mesobromium] grassland	B1.45	Atlantic dune Mesobromium grasslands	16.225	
Atlantic dune thermophile fringes	B1.46	Atlantic dune thermophile fringes	16.226	
Dune fine-grass annual communities	B1.47	Dune fine-grass annual communities	16.227	

Species that depend on the habitat

A number of characteristic dune species are supported by the habitat and, more importantly, the habitat mosaic of dune systems. Both *Lacerta agilis* (sand lizard) and *Bufo calamita* (natterjack toad) – listed in the Habitats Directive - depend on the open character of the fixed dune habitat for at least part of their range. Management guidelines for both species have been prepared in the United Kingdom as part of a national 'Species Recovery Programme' (Beebee and Denton 1996, Moulton and Corbett 1999).

Lacerta agilis has two key habitat requirements across its range;

- Insolated (exposed to the sun) and predominantly south-facing mature heath or dune habitat with varied vegetation structure for cover, for hunting and to allow the species to regulate its temperature, and;
- Un-shaded, predominately south-facing areas of exposed sand for egg incubation

Whilst the preferred habitat in the United Kingdom is within thick tussocks *of Ammophila arenaria* within the semi-fixed dunes, the species also occurs in suitable habitat within the fixed dunes and heaths where there is between 5-20% bare sand. Similar habitat requirements are noted for Sweden (Berglind 2007).

Bufo calamita is associated with breeding in warm, shallow, seasonal dune pools but the terrestrial habitat is of equal importance as it is used by the species most of the year. This needs to be open, with short vegetation to allow easy movement. The maintenance of the open character of the habitat through regular disturbance is important (Andrén and Nilsson 2000).

Bare sand is a vital component of grey dunes for many invertebrates such as aculeate hymenoptera, dune tiger beetles (*Cicindela maritima* and *C. hybrida*) and some spiders such as the wolf spider *Arctosa cinerea* and crab spider *Philodromus fallax*.

Small patches of bare sand throughout the fixed dune habitat in France provide a niche for *Omphalodes littoralis* (Habitat Directive Annex II species). The species is at risk from the spread of scrub and trees and is subject to conservation programmes. Studies have shown that the species thrives in areas of rabbit activity where there is disturbance of the soil but not large-scale re-mobilisation of sand.

Anthus campestris (tawny pipit, listed in Annex I of Birds Directive) has an unfavourable conservation status in Europe (BirdLife International 2004). It is widespread over the continental parts of Europe but a declining trend has been recorded for a long period in large parts of its breeding range. It is confined to habitats characterised of dry, sandy soil with bare patches, often early succession stages dependent on continuous disturbance (Elfström 2007). In north-western Europe (including Denmark and south Sweden) fixed dunes are one of the main habitats where these requirements are met.

Related habitats

Grey dunes are part of the mosaic of habitats in dune systems. It is often difficult to map precisely where 'grey dunes' (2130) blend into decalcified dunes (*2140), dune heaths (*2150) and Mediterranean dune grasslands and juniper scrub (2210, 2220, 2230, 2240 and 2250). Fixed dunes also merge with dry slack habitat types (2170 and 2190).

They lie, in the sequence of vegetation community succession, between the more dynamic communities of the mobile and mainly shifting dune zone (yellow dune) and the scrub and dune woodland zone. They form the matrix within which the humid dune slacks sit and erosion of fixed dunes may lead to secondary slack formation. The broad habitat type (*2130) includes both calcareous and acidic dune grasslands and overlaps with humid dune slack habitats particularly through the habitat 'dunes with *Salix repens* ssp. *argentea*' (2170).

In large dune systems there will be transitions between dune communities of the wet (hygro-/hydrosere) and dry (xerosere). Grey dune is found in close association with dune heath (habitat type *2140), especially from the Netherlands northwards to Denmark and the Baltic. In Germany it often occurs on south slopes in association with the Empetrum heathland of the north slopes (Isermann, pers. comm.). In Denmark the distinction is difficult and the term 'fixed dune heathland' might be more applicable. Traditionally the decalcified dunes (*2140) were grazed but common dune grazing ceased about 50 years ago. In the last 150 years drifting sand has been eliminated by reforestation, restrictions on grazing and planting of *Ammophila arenaria* (Pihl *et al.* 2001). The characteristic species of the decalcified dune heath are *Calluna vulgaris* (heather), *Empetrum nigrum*, and also *Deschampsia flexuosa* .

Ecological services and benefits of the habitat

A broad fixed dune zone, together with the first high, mostly mobile dune ridges, forms the main coastal defence along much of the coast from the Netherlands to Denmark and along the Baltic from Denmark to Poland and eastwards. Where the dune zone is high and broad this will also hold a freshwater aquifer and, along low-lying coasts this will prevent salt-water intrusion into the polder-land.

The dune aquifer along much of the North Sea coasts has been exploited for water supply. Extraction continues to be a significant source of fresh drinking water in the Netherlands, Germany and Denmark. Care needs to be taken not to over-extract. In the Netherlands pre-treated river water is infiltrated into the dune system where the filtration properties of the sand are used to provide clean drinking water.

The fixed dune landscape gives scale to the dune coast and, in addition to the beaches, can provide an important recreational resource, especially for walking, cycling and horse-riding. In countries such as the Netherlands, Denmark and Latvia the open dune landscape is a vital element for outdoor recreation. Almost all dune managers will have an element in their work to provide for access and recreation: in the 1980s the focus of management was often on recreation rather than nature.

Trends

The general trend from an ecological and geomorphological perspective is towards increasing stabilisation and succession towards rank grasslands, heathlands, scrub and woodland.

To take the example of the United Kingdom, there is little doubt that large losses have occurred due to agricultural (including afforestation), industrial and urban developments. Overall, however, there has probably been a trend over the past 50 years of increasing grey dune habitat, but mainly to old stable, acidic stages. This relates to the fact that dunes have become much more stable over this period. Newborough Warren in Wales, for example, was much more mobile in the 1950s with mobile dunes occupying over 70% of the site as opposed to just 6% today (Rhind *et al.* 2001). Similar trends are seen in the German Wadden Sea Island of Spiekeroog, where semi-fixed grey dunes (the younger succession stages) have decreased, and heathlands, dominant grasslands, scrub and woodland have increased (Isermann and Cordes 1992).

However, significant areas of grey dune habitat have also been lost to the development of conifer plantations, particularly in Denmark. In Wales, for example, plantations cover approximately 21% (1700 ha) of the dune resource, and of this, a large proportion would have included grey dunes (JNCC 2007).

The national reports under Article 17 of the Habitat Directives will address trends in the range, area and condition of fixed dune habitat. The national report for the United Kingdom (JNCC 2007) reports that the range is stable and the area increasing but that specific structures and functions (and typical species) and future prospects are unfavourable-bad and deteriorating. For the United Kingdom a large part of this habitat is expected to remain in unfavourable condition: 53% of SCI area, representing 21% of the total UK resource (JNCC 2007).

Threats

Across Europe fixed dunes have been, and still are, the most threatened and exploited part of the dune system. A significant part of the resource has been lost to tourism and residential development and sites are often fragmented by infrastructure and impacted by coast defence works. In Spain urban development has been the main threat to dune systems over the last 40 years (Ley, pers. comm.) Dune systems continue to be threatened or affected by pressures for hotel, golf course and residential development, misuse (e.g. off-road recreation vehicles) and the intensity of recreation pressure. Currently, these problems are of particular concern in the Baltic, Mediterranean and Black Sea Regions.

The following problems can be identified.

Decreased grazing pressure and loss of traditional grazing management practices can lead to:

- Succession to scrub development and dune woodland (on sites where this is a negative development)
- Over-stabilisation of the dunes and loss of bare sand patches
- Loss of heterogeneity at local and landscape level
- Loss of species diversity, especially of typical dune species

The impact of nitrogen deposition adds to the problems above and leads to:

- Further grass encroachment in dry dunes and the expansion of common grassland species
- Moss encroachment, for example *Campylopus introflexus*
- Spread of ruderal species
- Loss of calciphilous species in dry dunes

The consequences of coast erosion:

- Fixed, and especially semi-fixed dune habitats become squeezed between advancing mobile dunes and dune scrub, and often development on the back dunes
- Direct loss of habitat
- Fragmentation of habitats

The direct and indirect impact of human activities:

- Coast protection and dune stabilisation
- Urbanisation and infrastructure development
- Land uses including golf courses and military training areas
- Tree plantations (of pines, Eucalyptus and Acacia)
- Invasion of non-indigenous trees, shrubs, vascular plants and mosses in open dune areas
- Introduction of large numbers of exotic species arising as escapes from gardens
- Off-road driving

- Rubbish dumping
- Impact of recreation pressure (including dogs)

As with many semi-natural habitats it has been the loss of traditional management practices which has had most impact on the evolution of the dune systems from the dynamic state to the stable state. From both ecological and geomorphological perspectives the heterogeneous and dynamic dune landscapes are perhaps more 'exciting' than stable and 'fossilised' dune landscapes. Yet, there is a common history across Europe of over-exploitation and neglect of dune areas in the Middle Ages leading to excessive sand-blow and damaging sand drift. Since the 16th Century in Denmark, for example, authorities put restrictions on grazing to prevent sand-drift. But now almost half of all sites in Denmark are grazed again (Pihl *et al.* 2001), recognising, that, when controlled, grazing can be sustained.

Main reasons for problems in dune management are described below.

Lack of grazing

Short species-rich grasslands are characteristic of fixed and semi-fixed grey dunes. Bare sand patches and differences in soil conditions (moisture, nutrients etc), topography, aspect and slope all contribute to this diversity. With natural succession the open character would be replaced by a continuous sward of grasses and the establishment of first scrub and then woodland. One may assume that in pre-historic times natural grazing pressures were able to maintain patches of open dune grassland and bare sand to allow the characteristic fauna and flora to survive.

Grazing has been the single most significant land management activity for maintaining the open character of fixed dunes for centuries, especially in northern countries (e.g. de Bonte *et al.* 1999). Particularly important in North West Europe was the introduction of the rabbit (*Oryctolagus cuniculus*). Most of the large dune systems in the United Kingdom were warrens (deriving from the old French word warenne meaning an enclosure for game). Rabbits were introduced to the German Frisian Islands some 800 years ago (Mühl 1999). Dune land in England could at one time be valued by the number of rabbits it could support.

The Flemish dunes (in North France and Belgium) as well as the dunes of the German Frisian Islands were, for centuries maintained as an open landscape by rabbits, domestic livestock grazing (including cattle, donkeys and sheep) and by the cutting of firewood (e.g., Leten *et al.* 2005, Lemoine 2005). The thick dune grasslands of north-west France are known as the 'mielles' reflecting their quality as pasture-land (Géhu 1985). The open dune landscape is thus a semi-natural habitat. The 'invasion' of indigenous scrub is therefore a natural phenomenon. In Belgium the distinction is made successionally between primary scrub, of *Hippophaë rhamnoides* (sea buckthorn) and secondary scrub, of *Ligustrum vulgare* (wild privet) and other species.

Rabbit activity, including grazing, burrowing, trampling and dunging, are all important factors in the maintenance of the habitat and its heterogeneity. Rabbit populations were almost entirely wiped out by the widespread introduction of the myxomatosis virus in the 1950s. This was followed by changes to the vegetation (Ranwell 1963) and an explosive growth of scrub on many sites. From the 1990s the rabbit populations have also been affected by the Rabbit Viral Haemorrhagic Disease (RHVD). During the last 150 years on the Dutch and German Frisian Islands there have been cyclic changes in population density due to changes in hunting intensity and diseases such as myxomatosis and RHVD (Drees 2004). In 1990 the population on the Frisian Islands collapsed and since 2003 the population has stabilised at a lower level (Drees 2007).

The loss of rabbits from the dune systems of north west Europe has led to a decrease in the small-scale dynamics of the grey dunes (van Til and Kooijman 2007). Species richness is highest at intermediate levels of rabbit pressure (Zeevalking and Fresco 1977, Isermann *et al.,* submitted). This grazing activity induces spatial heterogeneity and maintains succession stages with high numbers of species (Gibson 1988). It is rabbits, therefore, which have an indispensable role to play in the recovery of such dunes.

Nitrogen deposition – nutrient enrichment

Nitrogen deposition above historic background levels remains a particular concern for nutrient poor dune systems. Although total levels of pollution are now falling due to improved emission controls there may be a build up of a 'nutrient pool' in both above ground biomass, the soil organic matter and soil-bound ammonium. The result is an increase in vegetation growth, especially the coarse grasses such as *Ammophila arenaria*, *Calamagrostis epigejos* (small wood reed), *Arrenatherum elatius* (false oat-grass), *Carex arenaria* and *Deschampsia flexuosa,* which have become dominant in many dry dune grasslands since the 1970s (Ten Harkel *et al.* 1998).

A considerable amount of management activity in dune systems has been triggered as a result of this problem. Grazing by large herbivores can reduce the biomass of grasses and shrubs and can counter the negative effects of atmospheric nitrogen deposition on plant species-richness (Kooijman and Van der Meulen 1996, Ten Harkel and Van der Meulen 1996, Boorman 2004).

The threshold for the amount of nutrient deposition will vary from dune system to dune system. In the Netherlands studies have indicated that levels increased from c.10 kg N ha^{-1} yr^{-1} in 1930s, to c. 25 kg n ha^{-1} yr^{-1} in 1980s and were between 25-35 kg N ha^{-1} yr^{-1} in the late 1990s. It is generally considered that values of up to 10kg N $ha^{-1}yr^{-1}$ are safe with a critical load for the United Kingdom lying somewhere between 10 - 20 kg N ha^{-1} yr^{-1} (Jones *et al*. 2004) and for decalcified dunes in Denmark 10-15 kg N ha^{-1} yr^{-1} (Pihl *et al.* 2001). Higher loads will promote the growth of fast growing plants and can stimulate acidification. The most sensitive areas are lichen-rich dry dunes (northern *2130 and *2140). In Denmark current levels of nitrogen deposition (6-15 kg N ha^{-1} yr^{-1}) lie close to the critical load for lichens and above historic levels (of between 2 -5 kg N ha^{-1} yr^{-1}).

Nutrient enrichment can also arise from local sources such as adjacent agricultural land, sewage treatment works and springs. Combined atmospheric and groundwater inputs of nitrogen should be assessed when determining nitrogen budgets for individual sites (Jones *et al.* 2005).

Sand supply, coastal erosion and coastal squeeze

Many parts of the European coast are suffering from a shortage of sediment supply and space resulting in 'coastal squeeze' (European Commission 2004). Dune systems may be affected by erosion caused by natural and human induced factors. On some sites fixed and semi-fixed dune habitats are caught in a squeeze between advancing dune sheets (often the natural response of the system to coastal erosion) and scrub or woodland advance.

In many situations woodlands may have been planted to stabilise the dunes or give shelter to local residential communities developed on the back dunes. Similarly many fixed dune habitats are cut off from the sand supply by infrastructure and coastal defence works. This has been identified as a particular problem in France where the fixed dune belt may be a narrow zone between the mobile dunes and the forest. Similar situations occur along much of the Baltic coast, where the coastal protection system often is represented as a beach-dune-forest complex.

Current human impact on fixed dunes

In countries such as Spain development pressures continue to impact on dune systems. There is a need for better coordination between national, regional and local administrations to ensure that development does not ignore the natural values of dune systems (Ley, pers. comm.).

Many dune systems are modified to increase their role as sea defence structures. Along the mainland coast of the Netherlands the management of a high, engineered sand-dike reduces the action of wind. Similarly in Denmark the natural dynamics are reduced by coast protection works.

Fixed dune habitat can be maintained in isolation to coastal processes. Much of the resource lies beyond the influence of coastal processes and the 'sand spray' (the 'rain' of sand which is a feature of exposed dune systems) but bare sand can be maintained within the system to provide some internal dynamics.

Human activity leads to the introduction of non-native species to dune systems. Several of these cause particular management problems. For example, in the last 5-10 years, on the German Wadden Sea Islands, the spread of *Prunus serotina* (rum cherry) has been studied. This will probably be a problem in the future (Isermann, pers. comm.). On the Sefton Coast, northwest England, a band of boundary vegetation with high incidence of garden-sourced exotic species was found to exist wherever housing development was adjacent to the dunes (Edmondson, pers. comm.).

An important aspect of the management of dune systems is the management of recreation. Sometimes there is a need to control the pressure moving inland from recreation beaches as holiday-makers seek shelter and quiet spots. More commonly, in managed coasts, there will be a formal recreation infrastructure guiding visitor pressure from the back of the dune system to the prime destination, the beach. Increasingly, however, as in the Netherlands, it is the dunes themselves which are the focus for the recreational activities and management has to provide for, and segregate, access for vehicles, pedestrians, cyclists and horse-riders. Trampling does affect the dune system (Boorman and Fuller 1977, Isermann and Krisch 1995) but intermediate trampling can support species richness (Andersen 1995).

Climate change effects

Dune systems are a product of climate and the activities of people. In Denmark the overgrazing of dunes more or less coincided with the Little Ice Age in the 1500s, probably causing the massive movements of sand which affected the landscape for centuries. In the absence of man most dune systems would probably be dominated by forest (Pihl *et al.* 2001). Although many dunes systems have become increasingly stable over the last century their inherent dynamic nature may allow them to respond to climate and sea level changes by re-working dune forming sediments.

Climate change will have an impact on dune systems throughout Europe, in terms of impacts of sea level rise and increasing temperature. Using available climate change scenarios there are likely to be very different responses on Mediterranean, Continental and Atlantic dunes (van Huis 1989, van der Meulen *et al.* 1991).

The potential impact of climate change and sea level rise was studied for a dune system in Denmark (Vestergaard 1991). The possible effects of increased aridity and prolonged growing season, due to increased temperatures are expected to influence dune vegetation and soil by:

- Favouring xerophytes in competition with mesophytes. For example, deep-rooted xerophytes such as *Ammophila arenaria* may be less influenced by increased aridity than species with superficial root systems such as *Corynephorus canescens*
- Changing the phenological relationships between the plant species which in turn affect the food supply for animals
- Causing immigration of southern species and depression of more northern and Atlantic species
- Causing a decrease in soil leaching and increase in litter decay rate and mineralization, improving the nutrient economy of the dune habitat

The scenario may also favour the establishment of exotic species and could have effects on primary production (Isermann, pers. comm.).

An increase in sea level could affect dune systems by stimulating the erosion of dune systems (even those which are currently accreting) leading to greater instability and also by changing the groundwater regime. There may be a balance between a decline in groundwater level caused by the narrowing of the dune system due to erosion and a rise in groundwater caused by the rising sea level (Vestergaard 1991).

Climate change is considered a major long-term threat to the future condition of fixed dune habitat (JNCC 2007). Sea level rise will trigger a geomorphological response (Pye and Saye 2005). The majority of dune sites in Wales have increased in size in the last 100-120 years (Pye and Saye 2005), a pattern consistent with a trend for net sediment accumulation in estuaries over the same period. Based on an assumed sea level rise of 0.41m by 2100 it is predicted that several sites will experience significant loss of dune area and habitat over the next century, but that some sites will continue to accrete, and for others there will be little net change (Pye and Saye 2005).

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. To make the best choices dune managers need to develop a basic understanding of how dune systems 'work' and how external factors such as atmospheric nutrient deposition 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 the Coastal Union-EUCC (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 .

Dune conservation manuals published in the 1980s (e.g. Agate 1986) tend to focus on dune stabilisation and access control techniques. A dune management manual relevant to the whole of the European coast is yet to be published: general advice country-by-country usually forms part of the development of management plans for Natura 2000 sites.

The decision-tree developed through the work of a LIFE-coop project (LIFE03NAT/CP/NL/000006) is based on two distinct types of fixed dunes, those that are **stable** (and perhaps have been for many decades or centuries) where sustained levels of management are required to maintain dune grasslands and those which are **dynamic** (where there is a equilibrium between factors which act to mobilise sand and factors which act to stabilise sand). Many dune systems fall between these extremes. In the model these are termed 'fixed dunes' and the management choice can either be directed towards dynamic dunes (generally preferred) or towards stable dunes.

The most significant complicating factor in the decision-tree is the amount of and the effect on soils and vegetation of Nitrogen deposition. Understanding to what extent a dune system has already been affected by Nitrogen deposition helps to narrow down the range of choices for management.

Stable dunes would naturally revert to scrub and woodland. This succession is arrested by cutting, grazing, burning and bioturbation (the mixing of soil layers by burrowing animals). The most important management goal for Natura 2000 is to maintain species-rich short grasslands, within which the activity of rabbits, ants and other animals such as rodents maintain some bare ground, vital for heat-loving fauna and annual plants (dune ephemerals). Some scrub and woodland, especially species-rich scrub on calcareous soils should be accepted to provide a habitat for birds and increase landscape diversity. Eventually, however, most grazed dune grasslands will turn to dune heath by the decalcification of the soil.

In dynamic dunes there may be a mosaic of habitat types; shifting dunes, stable but open dunes, young slacks, fixed dunes and scrub. A balance can be maintained between large-scale dynamics and succession. Grazing and human activities also act to slow down succession and maintain mosaics.

Factors which disturb this equilibrium are a threat; tree plantations, decreased grazing pressure (but see above), changes in traditional management etc. These may lead to positive feedback mechanisms: more vegetation leads to more vegetation. Across much of north west Europe there has been a shift over the last 100 years from situations where the dunes could be considered to be too dynamic to a situation today where most are considered too stable (e.g. Rhind *et al.* 2001, Boot and van Dorp 1986, Packham and Willis 2001, Arens *et al.* 2005).

In addition to its effects on established swards increasing the input of Nitrogen to the dynamic dunes can seriously disturb the equilibrium by encouraging increased growth of algae (algal crusts are a key factor in stabilising blow-outs), mosses and coarse grasses. The response to increasing Nitrogen loads has to be an increase in management intervention (mowing, grazing, cutting, burning and turf removal) in order to maintain habitat quality.

The 'fixed dune' situation is an intermediate stage in the model proposed by Brouwer *et al.* (2005). The management choice is either to intensify the management or accept the gradual move towards an ecologically and geomorphologically stable situation. There are biodiversity and landscape considerations here; the dynamic dune is richer in biodiversity of different scales and is also a 'wilder' landscape. On the other hand, some older stable dunes preserve medieval landscapes and the agricultural fields associated with early settlement patterns. A wider regional or national context may be an important consideration in developing a vision for the site. Managers need also to remember that dunes are often cultural landscapes, formed through centuries of interaction with local land uses. This cultural link can also perceive blown sand as a threat and communities are often divided in their views on the desirability of mobile sand.

Large scale destabilisation can be an effective management tool but runs the risk of losing populations of species which depend on habitat mosaics. The opposite to this approach might be considered to be 'eco-gardening'; creating and maintaining patches of bare sand where large-scale dynamics are absent. There is no simple solution and some of the results of recent experiments are discussed under restoration actions.

Active management

Grazing

Extensive year-round grazing is probably the most appropriate management technique across most of the fixed dune resource from the lush dune grasslands of the Atlantic fringe to the more sparsely vegetated grey dunes of the Continental and Mediterranean climates. Dune systems will have been influenced by native herbivores (rabbits, hares, deer etc.) and by a wide range of domestic grazing animals dependent on local tradition. In most areas, without this activity (probably combined with scrub cutting –see below), there would be a gradual move towards scrub and wooded habitats.

Grazing can be used both as a recurring management tool and as a restoration tool with different grazing regimes applied for different objectives. Several reviews and guidance documents on grazing of dunes have been published (Oosterveld 1985, van Dijk 1992, Boorman and Boorman 2001, Oates *et al.* 1998).

These experiences conclude that grazing animals such as cattle and sheep, especially the mixture of animals, for example in Belgium (Provoost *et al.* 2002), can be used to counteract grass and scrub encroachment. Browsing animals such as goats are effective in countering the development of scrub and have been used in restoration projects. The effect of grazing depends on the mechanism which has led to the current state. If it is the result of reduced grazing pressure then it should be possible to return the habitat to its former condition. But in the case of existing dense shrubland, grazing alone is not successful, and at first scrub removal is necessary (van Dijk 1992). If however there has been an accumulation of organic matter the vegetation will remain more dense. This is also true for areas of high Nitrogen deposition.

Where organic matter has accumulated it may be necessary to combine grazing with another measure such as turf stripping or to intensively graze the site for a short period. Sometimes, however, there can be a difficulty in seeking to 'overgraze' using agri-environment funding as levels are often pre-determined by national policy.

Grazing is returning once again in northwest Europe as the main management tool to maintain the open character and diversity of sites. In south Sweden sandy fields and dunes were traditionally used as low productivity pastures (Appelqvist *et al.* in press) Today attempts are being made to reinstate grazing. To some extent the grazing is seen as a double-edged sword: grazing seems to stimulate lateral shoot formation in grasses thus creating dense grass swards and reducing the number and sizes of patches with bare sand. The view in Sweden is that ideally grazing should be carried out in a way that allows the animals (preferably of different species) to roam freely over a large area to create a mosaic of well grazed patches as well patches with taller vegetation. The grazing pressure should be moderate in the summer but can be higher in the autumn and winter (Appelqvist *et al.* in press).

The success of grazing management will depend on the type of grazing (single species or mixed), the breeds selected, grazing density, seasons etc. Grazing management is partly a trial and error approach, subject to the vagaries of seasons, but, as a management tool, must also be a long-term decision.

A positive spin-off from conservation grazing is that often it is the traditional (and rare breeds) which are most effective at tackling the coarse vegetation. The Forum for the Application of Conservation Techniques (FACT 2003) gives ratings for each species in terms of their ability to tackle scrub. Organisations exist in the UK, the Netherlands and France to promote the use of rare breeds in conservation (e.g. GAP 2001).

Table 2: Some examples of species used in conservation projects on fixed dunes drawn from the experience in the United Kingdom

Site	Species /breed	Stocking rate	Seasons	Comments
Ainsdale Sand Dunes, England (Kimpton, pers. comm.)	Herdwick Sheep	2 sheep /ha. c. 0.3 LU/ha	Winter (October-April)	Controls *Hippophaë rhamnoides* and birch. Existing stands of scrub must be cut and cleared.
Newborough Warren, Wales (Sandison 2005)	Welsh Mountain Ponies	1 pony /3-4 ha c. 0.25 LU/ha	Year round	Maintains short grass sward. Does not control scrub.
Sandscale Haws, England (Burton 2001)	Herdwick sheep Swaledale Mule sheep Friesian /Hereford cattle	c. 300 sheep on c. 250ha. In winter. 150 ewes and lambs in summer 60-70 cattle	Winter and summer sheep flocks Cattle grazed all year	Combined grazing creates tight, closed, species-rich sward. Some supplementary feeding in winter
St. Aidens dunes, Northumberland (Redgrave, pers. comm.)	Exmoor ponies	2 ponies /8 ha. 0.25 LU/ha	Winter grazed (October-March)	Grazing maintains matrix of short (species-rich) and rough dune grassland
Sandwell & Pegwell Bay National Nature Reserve (Swandale, pers. comm.)	Exmoor ponies	8 ponies /8 ha. I LU /ha.	Winter-grazed	Grazing on ancient dune pasture. Grazing only partly effective in controlling scrub.
Whiteford Burrows National Nature Reserve, south Wales (Musgrave, pers. comm.)	Welsh mountain ponies	50-60 ponies on c. 150 ha.	All year-round	Problems with sheep encroaching from adjacent common land

Note: The use of livestock is measured in generalised European Commission livestock units (LU) where cattle over 2 years old and horses are 1 LU, cattle up to 2 years old are 0.6 LU and sheep are 0.15 LU. In practice different breeds have different mature live-weights and conservation grazing schemes often use medium and small breeds. Additional guidance will be given through the individual agri-environment schemes.

For conservation grazing the main decision lies between year-round low intensity grazing or more intensive seasonal grazing. Boorman and Boorman (2001) propose that dune grassland can be maintained at low levels of grazing (0.06 -0.3 LU/ha) but a higher intensity will be required for restoration projects.

Grazing projects need to be supported by monitoring both to detect whether the desired effects are being achieved but also to check whether the action is having a negative effect on sensitive species such as reptiles, butterflies and some plants.

It is now possible to evaluate the success of some of the early schemes. In 1985 extensive cattle grazing was introduced to the Eiland van Rolvers part of the Amsterdam Water Supply dunes (van Til 2006). Cattle grazing initially led to a varied vegetation with blow-outs, dune grasslands and open dune scrub, but could not prevent woodland development in dune slacks. Also, by the 1990s the coverage of coarse grasses and scrub began to increase, probably enhanced by a decline in the rabbit population. The grazing did not have a clear impact on ground beetles and butterflies, but had a negative effect on bird species which depended on *Phragmites australis* (common reed) in slacks for breeding. Grazing had positive effects on plant species, macrofungi, dung chafers, grasshoppers and dragonflies. The studies concluded that grazing with large herbivores was successful, but that rabbits play an indispensable role in the maintenance of the coastal dune landscape.

Attempts to reinstate rabbit populations are difficult especially where the vegetation has grown coarse. In the 1980s rabbits were released on the Murlough National Nature Reserve in Northern Ireland but it was necessary to bring sheep on to the site (at 1.6 sheep/ha/yr) to create the conditions suitable for the expansion of the rabbit population (Oates *et al.* 1998).

Some studies (e.g. Nijssen *et al.* 2001) show how grazing, introduced to control *Calamogrostis epigejos* could have a negative impact on the very open *Corynephorus canescens* grasslands (intolerant of trampling) by replacing this with a *Festuca* spp. dominated grassland. This more closed sward would give a cooler micro-climate and could eliminate heat-loving species such as some carabid beetles (ground-beetles). It is suggested that these sensitive open vegetation sites may have to be fenced off from grazing pressure (Nijssen *et al.* 2001). More studies on the effects of grazing on fauna are required and care needs to be taken when setting up extensive grazing schemes.

In Belgium grazing has been introduced to maintain open areas after mechanical scrub control and to prevent scrub encroachment. (Provoost *et al.* 2004). The preliminary evaluation is that vegetation composition responds to grazing in a rather slow manner – over decades rather than years. Short-term effects have been studied through detailed projects on diet, habitat use and behaviour for different species (e.g. Konik and Shetland pony, donkey and Scottish Highland cattle). The results confirm that all domestic herbivores are mainly grass eaters (70-80% of their diet is composed of grasses and sedges) and they prefer to graze in grasslands. Diet is affected by season. During the winter and early spring cattle and donkey browse *Ligustrum vulgare* and *Salix repens*. But browsing pressure is insufficient to push back or to prevent scrub encroachment. *Hippophaë rhamnoides*, the most common scrub species, is hardly touched by the herbivores.

Grazing experiments in Belgium have shown that rough vegetation, dominated by *Calamagrostis epigejos*, which succeeds in patches of decayed scrub, is controlled and the impact of grazing is significant. In most cases the biomass of the dominant grass species collapses and after 3-4 years several stress-tolerant dune grassland species occur (Provoost *et al.* 2004). Colonisation by dune species is promoted by both the trampling effects of grazing animals and by seed dispersal through dung.

The overall conclusion seems to be that the benefits of grazing will outweigh negative side-effects, but that for many sites more attention should be given to maintaining rabbit populations and that grazing alone will not counter all the problems associated with scrub development.

Burning

There is increasing interest in burning as a management tool on calcareous dunes. The technique has been applied with success on the more acidic dunes in Denmark (mainly of habitat type 2140) and is being trialled on calcareous dunes in the Netherlands through the LIFE-Nature project 'restoration of dune habitats along the Dutch coast'

The Danish experience is that burning dune heath in a mosaic pattern of small irregular patches (burning of small patches of 0.1-1 ha on a 5-15 year rotation) is a very efficient management tool, also in undulating terrain (Final report LIFE-Nature project LIFE02/NAT/DK/8584). To control the fire a narrow firebreak is cut with a tractor-mounted mulcher. Following this, a small counter-fire is started on the lee side of the belt before the actual fire is started on the windward side. The shape of the burned areas is undulating in order to create a more natural look. Burning mainly takes place in February and March, outside the bird breeding season. Delays can be experienced with weather. The reported cost was about €70/ha.

A study of the restoration of lichen diversity following a wildfire on the island of Terschelling in 1993 (Ketner-Oostra *et al.* 2006) found that fire alone will not change dunes dominated by grasses into open lichen-rich grasslands where there remains high Nitrogen deposition. In the years immediately after the fire, recovery of fixed dune vegetation was promising but the dominance of coarse grasses returned since the original factors which had developed the coarse grassland were still there:

- Nitrogen deposition in combination with available phosphates in the soil.
- The impact of acidification on the soil micro-organisms which influence the growth of *Ammophila arenaria.*
- Litter decomposition and soil formation during succession.

The recommendation from this study is that after fire, burned vegetation should be cleared and that fresh sand, either imported, or by re-activation of blowouts should be used to encourage the restoration of the fixed dunes.

There is a need for further studies on the value of burning as a management tool for the conservation of fixed dunes. It is a practice which would appear to present most opportunity in the calcium-poor dunes of the Wadden Sea area (Vestergaard and Alstrup 2001).

Mowing

Mowing as a recurring management practice is more commonly associated with dune slacks. Mowing of dune grasslands has been used in Belgium (Provoost *et al.* 2004) and on the Danish dune heaths (Final report LIFE-Nature project LIFE02/NAT/DK/8584). In Denmark tractor-mounted harvesters were used to mow vegetation as an alternative to grazing or burning. The reported costs were about €330/ha.

Managers at the Braunton Burrows dune site in south west England had to resort to attempts to mow the fixed dunes after negotiations to continue grazing failed (Breeds and Rogers 1998). Breeds and Rogers (1998) give details of a series of experiments with different types of equipment, none of which would replace grazing in an ideal situation. The main problem was the scale of the operation. In 1995/1996 140ha of dune grassland were mown but volunteers and staff could only remove 24ha of cut material. Problems affecting such work were using machinery in sand, uneven terrain, trenches and steep slopes and hidden hazards. Overall, after 10 years of work, the results did not compare favourably to grazing. The mechanical control was expensive and caused side effects such as compaction of the ground. Failure to remove the cuttings would lead to soil enrichment and burning on site caused problems with neighbours. The removal of cuttings off site would require a disposal area (Breeds and Rogers 1998).

Elsewhere, the mowing of 'semi-rough' is part of the management of 'links' (dune) golf courses and maintains fixed dune grassland in favourable condition. Many golf courses lie within the Natura 2000 network; the fine-tuning of normal management practices could help to conserve significant areas of fixed dune grassland and dune heath.

Sod-cutting

There is increasing interest in sod-cutting (also referred to as turf-cutting or turf-stripping) both as a restoration tool and a recurring activity. From a restoration perspective it can be used to remove the build up of below-ground biomass stimulated by Nitrogen deposition.

Recent experiments at the Amsterdam Water Supply dunes (van Til and Kooijman 2007) have developed a technique of shallow sod-cutting, removing a 5cm layer of topsoil. Cutting led to an increase in species such as *Viola tricolor* ssp *curtsii* (wild pansy*), Saxifraga tridactylites* (rue-leaved saxifrage), *Lotus corniculatus* (bird's-foot trefoil) and *Phleum arenarium* (sand cat's-tail) and a decrease in coarse vegetation such as *Rosa pimpinellifolia* (burnet rose) and *Calamagrostis epigejos*. The study also found an increase in grasshoppers in response to cutting and overall the action stimulated an increase in rabbit numbers, from low numbers up to 60/ha.

Further study will show whether the apparent benefits to the flora and fauna are short lived or sustainable. The technique may work because it avoids the pitfalls of taking off too much soil (and losing much of the seed-bank) and because it is applied in a patchwork so that there is little risk to populations of animals and plants which can colonise from nearby habitat.

Soil removal is often associated with scrub removal actions but the large volumes involved can be expensive to move and there is a risk that it may encourage further scrub invasion. However, if the problem being addressed is the build up of nutrient-rich top-soil then the action may be appropriate.

Soil reversal

A more disruptive technique which has potential benefits is deep ploughing and turning over the soil to some depth. In Sweden dune stabilisation activities have led to extensive vegetation cover followed by leaching of cations such as calcium and an acidified top layer of the dunes. This is perhaps more noticeable in the Swedish dunes as the sand mainly originates from siliceous bedrocks such as gneiss and granite and thus the soil pH was already relatively low.

To bring sand with a higher pH back to the surface an experiment has tested the use of different types of mechanical excavators to create relatively deep pits (2-3 metres deep). In areas with difficult terrain and steep slopes smaller diggers with caterpillar tracks have been used compared to larger wheeled excavators on flatter areas. Any additional disturbance which leads to blowout development is also welcomed.

To create patches of bare sand, the top layer of sand and turf including the vegetation was placed at the bottom of pits and the sand from the bottom layer placed on top, mimicking the effects of sand drift and presenting an opportunity to remove the rather extensive organic material. The initial results look promising (Bengtsson, pers. comm.): flowering plants are colonising the bare patches of sand and in some patches large colonies of sand-living insects, especially beetles and wasps, have become established after a short period of time. The management is relatively cheap; a large digger can produce several pits in one day on flat ground.

Topsoil inversion as a potential restoration technique for highly eutrophic hind-dune grassland has been trialled at Talacre Warren in north Wales, United Kingdom. The technique involved using a specially adapted plough to invert the soil profile, burying 30cm of topsoil under approximately 50cm of subsoil (Jones, pers. comm.)

Scrub cutting

Scrub is a natural component of dune systems and is a resource which has been exploited for centuries. However, since the 1950s many dune systems have recorded an invasion of scrub. Reasons include reduction in grazing pressure, loss of rabbit populations, water abstraction (especially for slack areas), nitrogen deposition and the loss of dynamics. The rapid and massive colonisation by *Hippophaë rhamnoides* recorded for the Belgian dunes (Leten *et al.* 2005), dunes of north France (Lemoine 2005) or for Germany (Isermann *et al.* 2007) may well be a normal process in lime-rich dunes in northwest Europe. This gives a management dilemma; to maintain species-rich open dunes or to accept natural scrub and woodland.

Policies for scrub management should be developed on a site by site basis. For Belgium, in some areas a strict policy of scrub eradication is developed to maintain the '19th Century' landscapes. At other sites a compromise is reached between pattern-orientated management (where intervention maintains the mosaic of habitat types) and process-orientated management where succession is accepted.

Experience of scrub control in Belgium gives the following best practice advice (Leten *et al.* 2005);

- Whether cutting of scrub is carried out by hand or machine it is important to remove and process coarse woody debris.
- Stumps, fine organic matter and topsoil should also be removed.
- There will need to be follow-up work and evaluation.

The conclusion is that cautious removal of scrub and litter and the introduction of extensive year-round grazing may be successful in restoring and maintaining fixed dune habitats. Various techniques have been used for the removal of scrub from manual cutting to the use of tractor-mounted flails and adapted arms of tracked excavators. Details can be found in Leten *et al.* 2005.

Scrub control in north France (Dune Marchand, Dune Dewulf and Dune du Perroquet) started in 1988 with the manual cutting of *Hippophaë rhamnoides*, *Ligustrum vulgare* and *Salix repens* (Lemoine 2005). In what is described as 'eco-gardening' patches of low scrub were cut manually and later mechanically over an area of 9ha. From this a larger programme of scrub clearance was developed using tractors and mechanical flails to cut and chip thickets of scrub up to 3.5m tall (Lemoine 2005).

For the United Kingdom examples of scrub management for *Hippophaë rhamnoides* are described in The Scrub Management Handbook (FACT 2003). This provides guidance to selecting management options.

Removal of invasive species

The most common 'problem' species of fixed dunes in northwest Europe is *Hippophaë rhamnoides*. It is native to most of northwest Europe including the east coast of the United Kingdom. Where it has been introduced as part of 19th Century dune stabilisation problems, often in association with conifer plantations (e.g. west coast of England) it has become highly invasive, especially in young slacks and open dunes. Management prescriptions have been developed in projects from the United Kingdom, Netherlands, France and Belgium.

Rosa rugosa (Japanese rose) is a widespread problem on many North Sea and Baltic dune systems. It became popular in the early 20th Century as an ornamental shrub and has been widely planted. In Germany, Jutland and in the Baltic it was also planted to stabilise dunes. The plant spreads both by vegetative propagation and by seed. Expansion of *Rosa rugosa* reduces species richness for example due to shading (Isermann 2007a, 2007b). In Sweden attempts to eradicate *Rosa rugosa* have been carried out using excavators (Bengtsson, pers. comm.). First experiments used a type of bailer attachment which uprooted the bushes but allowed the sand to fall back to the ground. The material was piled up for burning. However, in the following year it was clear that a lot of the root system had been left in the ground; the regrowth had to be treated by hand. The technique was improved by using larger machinery to take out more of the root system resulting in less problems with re-growth (but still some problems). The technique also had the advantage of more disturbance to the soil.

Removing of *Rosa rugosa* and other coarse vegetation has also been carried out using a large sifting machine normally used to separate roots and other organic material from agricultural soil. Sand and plant material were removed by a front loader and tipped into the sifting machine. The clean sand was then returned to the dune area by the front loader resulting in more bare sand patches and some sand drifting. The techniques look promising (Bengtsson, pers. comm.).

The invasion of the exotic moss *Campylopus introflexus* is a particular concern on the more acidic dunes of the Wadden Sea area where it threatens the lichen-rich fixed dunes (van der Meulen *et al.* 1987, Biermann and Daniëls 1997, Ketner-Oostra and Sýkora 2004, Hassel and Söderström 2005). In Denmark and The Netherlands removal of the moss carpet has been attempted.

In The Netherlands at a scale of 200 m^2 sod-cutting by hand was used to regenerate the natural lichen-rich *Corynephorus* vegetation, but after few years *Campylopus* was again dominant. The species was also dominant five years after fire. Management measures will be less successful until existing atmospheric nutrient deposition reduces. Moreover, chemical control with the herbicide Asulox was not successful (Rowntree *et al.* 2003). Furthermore, rabbits not only distributed *Campylopus* pieces stuck to the animals, but also created open areas by scraping, which could be colonised by the moss, because the moss often established at disturbed sites. Natural sand accumulation from more seaward dunes (with higher lime content) could be a natural measure against the spread of the moss (van der Meulen *et al.* 1987)

Restoration activities

General guidance can be found in the web-based resource 'Coastal Habitat Restoration –Towards Good Practice' (Doody and Pamplin 2003).

Removal of plantations

Probably the most significant interference with natural dune evolution across Europe has been the planting of non-native woodlands, principally conifer plantations. The main reason for afforestation, in countries such as Poland, Denmark, Sweden and the Netherlands, was to stop long-standing problems caused by sand-drift and the 'wandering dunes'. For this reason the hardy, but uneconomic, *Pinus mugo*, was used in Denmark along with *Pinus contorta*. The potential for commercial plantations came later.

In France the focus was on finding a productive use for the vast areas of Les Landes and here plantations of native *Pinus maritima* were used. The trees were the basis for the turpentine industry. Elsewhere smaller scale woodlands have been planted to reduce sand-drift, find a productive use for dune 'wastelands', to shelter agricultural land and as cover for hunting.

A number of LIFE projects have addressed the issues concerning dune forestry and the conservation of fixed dunes. In France the focus has been to ensure that a zone of grey dunes is retained between the mobile dunes and the productive forests. In the United Kingdom the focus has been on issues concerning direct loss of habitat, fragmentation and the impact on the water-table, and in the Netherlands there is interest in re-structuring the plantations to replace parts of the forest with native 'dune woodland'.

The largest effort in pine removal has been in Denmark, through the project 'Restoration of Dune Habitats along the Danish West Coast' where the encroachment of self-sown trees has been tackled on some 5000 ha of fixed dune and dune heath where over 500 ha of dense overgrowth (self-sown woodlands) has been removed and 390 ha of plantations have been removed and the dune habitats restored.

The costs for these actions (Final report LIFE-Nature project LIFE02/NAT/DK/8584) are €2320/ha for conversion of forest stands to open dune, €1210/ha for dense over-growth (tree encroachment of up to 50 years old) and €228/ha for the removal of scattered self-sown trees.

The best practice guidelines, developed largely for dune heath habitats, are also applicable to the removal of plantations from fixed dunes.

- Clearing of invasive exotic conifers should take place as soon as possible. The longer the trees develop the more difficult restoration will be.
- Clearing of conifers should always include the removal of all above-ground biomass, including the litter layer of needles and cones. The material should be collected on site and either burned on selected spots or chipped and removed from site.
- The manual removal of self-sown young conifers will be necessary every year for the first three years following clearance. Thereafter the manual removal will need to continue every few years until the seed bank is exhausted.
- In some areas extensive grazing (mainly by sheep, but also in some cases cattle) is recommended to maintain the open vegetation.
- The heavy equipment used should have wide, preferably smooth, tyres, using as few routes as possible and avoiding damage to the more sensitive humid dune slack communities. Heavy equipment can, however, be used to good effect to break up dense scrub to allow access to cattle.
- Fire spots should be carefully selected and should not be on grey dune habitat. It may be necessary to transport the cuttings to fire sites. Fire sites should be re-used, if necessary, in follow-up clearance.

Mechanical uprooting of pine trees has been tested in Sweden with good results (Bengtsson, pers. comm.). An excavator with a large gripping device has been used to pull out the whole tree including the roots. The method has been trialled on trees with a relatively small DBH (diameter at breast height) (c. 15-

30 cm) but probably can be used on larger trees as well. The uprooted trees are chipped and removed from site. The disturbance created by the techniques also provides patches of bare sand. An area of 2.5 ha was cleared in 120 hours at a cost of c. €2600/ha. The result was a nitrogen-poor dune habitat with large patches of bare sand restored in a few weeks rather than the much less interesting clear-cut vegetation that would have been the result from just felling the trees (Bengtsson, pers. comm.).

At Ainsdale Sand Dunes National Nature Reserve in the United Kingdom conifer removal has been followed up by sheep grazing (Simpson and Gee 2001). However, there are now concerns that sheep grazing produces a rather uniform, low vegetation and the site managers will introduce an experiment using Shetland cattle (a hardy, small breed) in an attempt to develop more structure and open up areas of bare, and blowing sand (Kimpton, pers. comm.)

The removal of conifers should be combined with either litter-raking or top soil removal (van Til *et al.* 2007). In an experiment in the Amsterdam Water Supply dunes different treatments were applied to the removal of a 60-year old *Pinus nigra* stand. The treatments were control, tree-cutting, tree-cutting with litter raking and tree-cutting with top soil removal. The best restoration was achieved with top soil removed. This eliminates the litter layer, increases pH and reduces the nitrogen content of the soil. If litter raking is used a further reduction of tall grass cover could be achieved by additional seasonal grazing by cattle or sheep.

Large scale destabilisation

Large-scale destabilisation and disruption of dune systems can allow a new habitat mosaic to form with, at least for a period, more open conditions and representation of younger stages of dune and slack succession. Projects which aim to create areas of bare sand have been carried out in the Netherlands (Arens *et al*. 2005, Arens and Geelen 2006) and France (Lemoine 2005). The main idea for restoring dune mobility is that natural processes will take control, creating new dune valleys with opportunities for pioneer species whilst destroying mature vegetation through burial (Arens *et al.* 2005). However, restoration of dune mobility in the fixed dune zone is difficult and even after 10 years it cannot be determined whether the technique is successful (Arens *et al*. 2005). The removal of vegetation and soil leads to a sudden and dramatic increase in aeolian dynamics but re-stabilisation from root remnants counters dune mobility. Also a 'pavement' of eroded (dead) roots prevents further erosion. The experiments in the Netherlands will be monitored for several decades (Arens and Geelen 2006).

Other relevant measures

Positive management of golf courses and military sites

A significant proportion of the fixed dune resource in the United Kingdom lies within the boundaries of golf courses and military sites, many of which were established in the 19th century. The undeveloped nature of the golf course 'roughs' and training areas has made these sites important for nature: many are included within the Natura 2000 network. Managers of these sites have worked closely with nature managers to share skills and develop conservation programmes (Simpson 2000, Simpson *et al.* 2001b) and management bodies, advisors and specific non-governmental organisations promote good practice. An overview of golf and the environment can be found on www.golfenvironmenteurope.org.

Recreation management

In all countries there is concern about the impact of recreation of fixed dune habitats but also an understanding that light pressure can be beneficial in maintain areas of open sand. In Denmark, for example, serious erosion is reported at 50% of fixed dune sites and erosion is noted at a further 33%. Of the 50% of reported cases erosion was considered to have a negative effect whilst in 20% erosion was considered positive. The number of paths networks is increasing, occasionally resulting in breaches in the dunes and blowouts.

The control of recreation pressures is commonly a feature of management projects in southwest and Mediterranean Europe where there is less of a history of control on dune activities, continuing pressures for development and the need to educate the visitors. In France LIFE projects have addressed grey dune conservation and sustainable tourism (e.g. LIFE95ENV/F/676).

In many sites the monitoring of recreational use is important to assess the impact of access and to plan annual programmes of maintenance.

Monitoring of habitat quality

Article 17 of the Habitats Directive requires Member States to submit regular reports on the condition of Natura 2000 sites and progress towards favourable conservation status. Whilst each Member State will set out its own targets for habitat quality these must allow an overall assessment of conservation status to be made by the European Commission every six years. In the United Kingdom the Common Standards Monitoring Guidance for national Sites of Special Scientific Interest is used as a basis for compiling reports under Article 17. The guidance for sand dune habitats, including fixed dunes, is published on www.jncc.gov.uk (JNCC 2004). For fixed dune grassland the following targets should be met:

- Bare ground or sand present, but no more than 10% total area
- 30-70% of sward to comprise species-rich short turf, 2-10 cm tall
- Flowering and fruiting of dune grassland frequent
- Typical species to be present
- Non-native species no more than rare
- Scrub/trees no more than occasional, or less than 5% cover
- Tree invasion from adjacent plantations rare

Special requirements driven by relevant species

There are concerns linked to the spread of grazing schemes and the potential impact on populations of reptiles. Although reptiles have undoubtedly benefited from the landscape mosaic created by traditional grazing some care needs to be taken to avoid known breeding sites. Intensive grazing can also reduce the micro-diversity of the vegetation and the habitat for reptiles such as *Lacerta agilis* and *Coronella austriaca* (smooth snake).

Guidance on habitat management for *Lacerta agilis* in the United Kingdom (Moulton and Corbett 1999) gives advice on management operations to avoid unintentional damage or disturbance to the species. Although whole site conservation is supported, management for *Lacerta agilis* in the United Kingdom is targeted to 'foci', known, stable, breeding and foraging areas. Most of these sites are well known so scrub removal can be targeted to maintaining the optimal conditions for the species and grazing projects and other initiatives can be made aware of the specific interest in parts of the site.

At some Swedish sites with *Lacerta agilis*, continuous mowing or grazing has been recommended in order to reduce overgrowth and to maintain patches with bare soil (Berglind 2007).

In the United Kingdom management work for *Bufo calamita* is focused on both the aquatic and terrestrial habitat. Terrestrial habitat has to be open, un-shaded with extensive areas of un-vegetated or minimally vegetated ground (Beebee and Denton 1996). Adult and juvenile *Bufo calamita* require this kind of terrain for hunting invertebrate prey which they do by active pursuit. They also need bare ground for burrowing. Management effort for the terrestrial habitat has been directed to the restoration of over-fixed dunes, creation of new yellow-dune habitat and maintenance of suitable dune habitat. (Beebee and Denton 1996)

In Sweden, grazing has been recommended in order to avoid overgrowth of sites with breeding pairs of *Anthus campestris*. There are also proposals to clear a zone inside the dunes from trees and scrub, as a complementary measure in order to restore the kind of dry heath on sandy soil that characterised the breeding habitats for this species in earlier days (Naturvårdsverket 2003, Elfström 2007).

In Estonia, at the Häädemeeste wetland complex, dune slopes were cleared of planted *Pinus mugo*, moss and lichen cover to improve the conditions for sand-dwelling insects, reptiles and bird species (Eglīte 2005).

Cost estimates and potential sources of EU financing

Specific cost features for the habitat

Management costs will vary depending on the objective for management. Funding for both the sustained management and the restoration of dune systems may be available through national agri-environment schemes and other national funding initiatives for nature conservation. Dune habitat management could also be linked to wider projects concerned with access, interpretation and eco-tourism. The EU Natura 2000 funding manual can be used to explore some of these possibilities.

Most Member States will have prepared specific funding packages for nature conservation and Natura 2000 sites and have an opportunity to set some priorities for the use of EU funds.

In England, for example, agri-environment funding is available to support the introduction and maintenance of grazing regimes on sand dunes (http://www.defra.gov.uk/funding/schemes/hls.htm). Support is also available for the creation of coastal sand dunes on arable land and grassland. Land that lies behind a sand dune and is currently arable, set-aside or grassland may be suitable to allow the roll-back of the dune system inland.

The prescription for fixed dunes is to manage by light grazing to control excessive growth of vegetation. Cover of scrub should be less than 5% and bare ground between 5%-15%. No supplementary feeding or application of fertilizers is allowed. The restoration option gives 5 -10 year periods in which to reach favourable or recovering condition.

Annual payments under the Environmental Stewardship Scheme are £140/ha (ca. €200/ha) for the maintenance of sand dunes, £200/ha (ca. €285/ha) for the creation of sand dunes on grassland and £320/ha (ca. €460/ha) for the creation of sand dunes on arable land. Other options, including access, may attract additional payments. Permissive open access, for example, could attract an additional £41/ha (ca. €60/ha).

Member States have opportunities to develop targeted management schemes for habitats and species. In Scotland 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. Annual costs for mowing and removal of material from dune grasslands are given as €600-750/ha, for a farmer to take material as hay €150/ha and to pay a farmer for grazing €70/ha but with costs decreasing over time.

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 2130:

- 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+ funds have to be studied 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 practise 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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