The Impact of Forestry on Coastal Geomorphology at Newborough Warren/ Ynys Llanddwyn NNR, SSSI, pSAC

Volume 1

Contract number: FC 73-05-18

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1.1 Introduction

This is the final report for a research contract FC 73-05-18 commissioned by the Countryside Council for Wales (CCW) to investigate the impact of forestry on coastal geomorphology at Newborough Warren. The project was commissioned following concerns that the forest was having a negative impact on the geomorphology and ecology at Newborough Warren/Ynys Llanddwyn National Nature Reserve (NNR) which is a Site of Special Scientific Interest (SSSI) and proposed Special Area for Conservation pSAC. The main concerns that this project addresses are:

1) The effects of forestry on beach and dune erosion.
2) The effects of forestry on the hydrogeology of Newborough Warren, winter flooding of wet interdune slacks and changes in vegetation within the warren.

The specific aims of this project are to investigate the impact of the forestry on coastal geomorphology, especially the problems of beach erosion and dune cliffing. To develop a hydrogeological model for Newborough Warren in order to investigate the effect of the forest on groundwater levels at Newborough Warren. As part of this research a baseline topographic survey of the beach and foredunes has been undertaken using DGPS in order to assess the problems of beach and dune erosion at Newborough Warren/Ynys Llanddwyn NNR. In addition, an investigation of the depth to bedrock beneath the dunes has been undertaken because bedrock will resist erosion and help to fix the location of the shoreline. This investigation included the collection of a geophysical profile across the warren and shallow drilling. The original aims of the drilling program were to determine the depth to basement beneath the sand dunes, especially along the beach in order to determine the thickness of sand and also to determine where bedrock would be exposed by coastal erosion. The exposure of bedrock on the foreshore would create natural hard points along the coast which would locally fix the coastline and reduce coastal erosion. However, following discussions with CCW and Forest Enterprise it was decided to relocate most of the boreholes to investigate potential permeability barriers within the dune sands as part of an investigation of the hydrogeology of the warren. Both the borehole data and geophysics have been incorporated into a hydrogeological model of the Warren. The aim of the hydrogeological model is to investigate the impact of the forestry on interception, evopotranspiration and the groundwater recharge.

The results of this project are presented in five reports:

1. An introduction to the effects of forestry on Coastal Geomorphology at Newborough Warren, this volume (Volume 1).
2. Shoreline monitoring at Newborough Warren (Volume 2).
3. Geophysical surveys at Newborough Warren (Volume 3).
4. Boreholes at Newborough Warren (Volume 4).
5. Hydrogeological model for Newborough Warren (Volume 5).

The reports are provided as text documents and as PDF documents on CD.

1.2 Newborough Warren

Newborough Warren is an area of coastal sand dunes at the south-western corner of Anglesey. It is surrounded by water on three sides with the Menai Strait in the southeast, the Irish Sea in the west, and Malltreath Estuary along the north-western side. Along its landward margin the warren passes into agricultural land around the village of Newborough. Newborough Warren is the largest area of coastal sand dunes in Wales and one of the most extensive coastal dune systems in Britain. It is a National Nature Reserve (NNR), Site of Special Scientific Interest (SSSI) and proposed Special Area for Conservation (pSAC). The designation for SAC includes:

1. Fixed dunes with herbaceous vegetation ("grey dunes") for which this is considered one of the best areas in the UK;
2. Dunes with *Salex repens ssp.argentea* for which this is considered to be one of the best areas in the UK;
3. Embryonic shifting dunes for which this is considered to be one of the best areas in the UK;
4. Humid dune slacks for which this is considered to be one of the best areas in the UK;
5. Natural eutrophic lakes with *Magnoptamion* or *Hydrocharition*-type vegetation for which this is considered to be one of the best areas in the UK;
6. *Petalophyllum ralfsii* for which this is considered to be one of the best areas in the UK;
7. Rumex rupestris for which this is considered to be one of the best areas in the UK;
8. Shifting dunes along the shoreline with *Ammophila arenaria* ("white dunes") for which this is considered to be one of the best areas in the UK;

Newborough Warren is the site where pioneering studies of coastal dune ecology were undertaken by Derek Ranwell (Ranwell 1958, 1959, 1960a, 1960b). It is also one of the sites where Landsberg (1956) compared the orientation of dunes with wind direction.

1.3 Geology and Geomorphology

Newborough Warren is an area of unconsolidated Holocene aeolian sands that overlie glacial deposits (till) which rest on Palaeozoic and Precambrian basement. The thickness of the sands across most of the site is believed to be between 10 and 20m although the sands pinch out against a basement rock ridge in the middle of the warren. The rock ridge is composed of Precambrian metamorphic sedimentary and igneous rocks including pillow lavas which outcrop on the beach close to Llanddwyn Island. The Palaeozoic rocks are not exposed but there are believed to be Carboniferous rocks beneath the southeastern part of the warren. The contact between the Precambrian and the Carboniferous rocks is not exposed but the strike runs from northeast to southwest parallel to the rock ridge. It has been suggested by Robinson (1980) that the river Afon Braint would once have flowed into Llanddwyn Bay and has been diverted by the beach and dunes to flow into the Menai Strait. As a consequence there should be a palaeovalley of the Afon Braint beneath the warren.

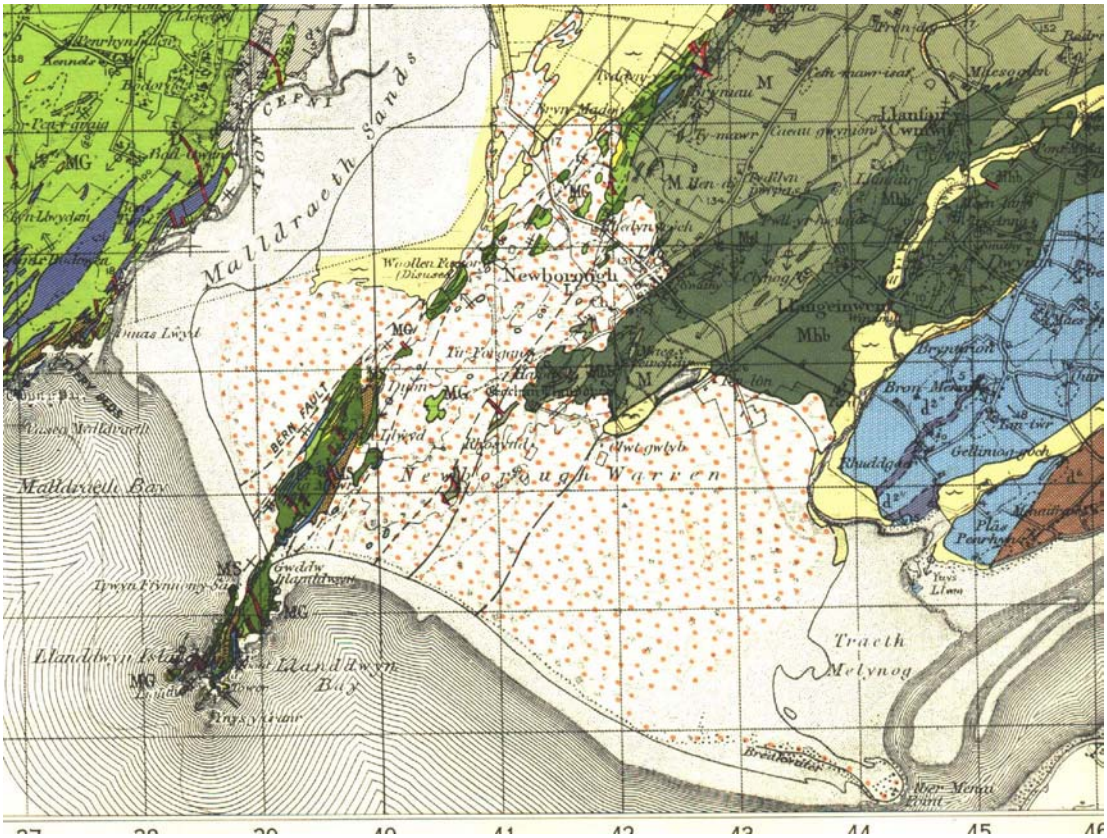

Figure 1. Geological Map of Newborough Warren, most of the area is underlain by Precambrian metamorphic rocks of the Mona Complex which includes Mica-schist (M) and Hornblende-schist (Mhb) of the Penmynydd Zone, spilitic lavas of the Gwna Group (MG) on Llanddwyn Island extending inland along the rock ridge. The eastern part of the warren is probably underlain by Carboniferous limestone and glacial till but there is no exposure of these within the warren.

Newborough Warren covers an area of approximately 1295 Ha (Ranwell 1958) of which 720Ha were planted with conifers, mostly Corsican Pine between 1947 and 1965 (Hill and Wallace 1989). The remaining 575Ha is largely open dune grassland and interdune slacks. The seaward side of Newborough Warren faces south west towards the prevailing winds and waves. There are two beaches separated by Llanddwyn Island which is connected to the mainland by a tombolo and ruined breakwater. To the north of Llandwyn Island is Traeth Penrhos which extends north towards the entrance to the Malltreath Estuary. To the south of Landdwyn Island is Treath Llanddwyn which extends southeast to Abermenai spit at the entrance to the Menai Strait. Traeth Penrhos is a sand beach with a relatively uniform slope. Traeth Llanddwyn is a mixed sand and gravel beach with large swash bars (Volume 2).

There are two main dune types at Newborough Warren, foredune ridges and parabolic dunes. There are two foredune ridges at Traeth Penrhos both of which are artificial having been created by Forest Enterprise using sand fences and brushwood to trap sand and create artificial dune ridges. The foredune ridge is currently being eroded at its southern end near Llanddwyn Island but shows evidence of active sand accretion including shifting dunes with *Ammophila*

arenaria at the northern end close to the Malltreath Estuary. South of Llanddwyn Island, Treath Llandwyn is backed by a steep cliff cut into dune sands due to recent erosion of the beach and dunes. Topographic profiles and a survey of the low water mark (Volume 2) indicate around 75m of beach erosion on either side of the Tombolo that connects Llanddwyn Island to the mainland. Further along the beach towards the visitors car park the beach has been accreting and the dune front is more stable. In this area there is a well developed foredune ridge which extends south and east along the coast to Abermenai Point. On the back beach, in front of the foredunes, are areas of embryonic shifting dunes. Further details of the frontal dunes and beach morphology including beach profiles can be found in Volume 2.

Inland, behind the foredune ridges Newborough Warren is dominated by compound parabolic dunes which form extended NW-SE trending dune ridges separated by broad interdune slacks. The compound parabolic dunes and interdune slacks are the main areas for fixed dunes with herbaceous vegetation, dunes with *Salix repens*, and humid dune slacks, for which this is considered to be one of the best areas in the United Kingdom. The dunes and interdune areas at Newborough are largely vegetated and stabilised at the present day although this was not the condition in the past when the dunes were much more mobile with areas of bare sand. The change in vegetation cover at Newborough Warren has been documented by Rhind et al. (2001) who describe a dramatic decrease in the area of mobile and embryonic dunes (75% to 6%) between the early 1950's and 1991. Reports by Greenly (1919) who compared Newborough Warren to the desert of Sudan suggest that the dunes may have been even more mobile at times in the past.

The age of the sands at Newborough is poorly constrained, a major inundation of sand occurred in 1331 when 75 Ha of land were buried by wind blown sand during a storm (Ranwell 1958). Recent optical dating of sand from a trench close to Clwt gwlyb (SH 4205 6440) indicates sand deposition around 1700 at a depth of 1.9m, and 1825 at a depth of 1.3m with two samples from depths of 0.9 and 0.7m giving ages of 1859 and 1859 respectively. A sample from 0.25m depth gives an age of 1886 (Bailey and Bristow 2000). In comparison C^{14} ages from the same trench at depths of 1.2 and 1.65m indicate ages of 240±40 BP and 450±60 BP, equivalent to 1655 and 1440 in calendar years (Bailey and Bristow 2000). Both sets of dates are internally consistent, that is they indicate samples with greater age at greater depth but there is a difference between the ages derived from the two methodologies, with the C^{14} suggesting that the sands are slightly older. However, both sets of ages indicate sand deposition since the reported storms in 1331 and this is consistent with later evidence of increased sand dune activity in the past.

In addition to the thin organic horizons within the sand shallow hand-augered boreholes around the warren by Turner (1999) located thin pebble horizons within the sands close to the beach which runs along the southwestern side of the site and there is evidence for thin clay layers associated with the estuary on the southeastern side of the site.

A water borehole drilled for this study encountered a peat at a depth of 10m. This peat underlies the dune sand and could provide a date for the initiation of Newborough Warren. Samples of this peat have been retained but not yet sent for C^{14} dating.

1.3 A Dynamic Landscape

In addition to the storm of 1331 when wind blown sand is reported to have buried 75Ha of farm land (Ranwell 1958) there are reports of active sand movement from the 17th and 18th centuries. Wortham (1913) states that manorial documents refer to encroachment of sand at Newborough in the time of Elisabeth 1st and again in the time of Charles 2nd . The first of these claims is supported by an injunction by Elisabeth 1st for the mayor and bailiffs of Newborough to punish whoever was found cutting, uprooting or carrying away marram (Owen 1952). Tutein-Nolthenius (1890) noted that whole mass of sand seemed to be moving at the end of the 19th century. Active dune migration continued into the early and mid 20th century when Ranwell (1958) measured the migration of dunes along six transects at Newborough Warren between 1952 and 1958, he recorded average annual migration rates between 1.5 and 6.7m per annum. The dunes that Ranwell measured are now totally static having been planted with conifers. The plantations of conifers at Newborough have fixed the parabolic dunes in place, preventing the natural movement of sand and the migration of sand dunes.

The mobility of coastal dunes is an important part of the ecology and geomorphology. The movement of sand dunes is constantly opening up new areas of bare sand for vegetation colonisation maintaining a natural succession of sand dune vegetation. The movement of sand dunes is accomplished by erosion and deposition of wind blown sand. In the case of parabolic dunes which are the dominant dune type at Newborough sand is eroded from the up-wind interlimb valley and blown over the dune crest to be deposited on the down-wind margin and dune apron. The wind erosion on the upwind interlimb valley causes deflation down to the water table. The water table restricts deflation because wet sand is much more difficult to entrain than dry sand. In this respect the elevation of the water table controls the wind erosion in interlimb valleys and the elevation of interdune areas. The wet interdune slacks which flood in the winter months are one of the features for which Newborough Warren is designated as an SAC.

1.4 A lost landscape

Historic aerial photographs of Newborough Warren and reports of early surveys by Greenley (1919) and papers by Ranwell (1958) describe active parabolic dunes at Newborough Warren. The growth of trees on the parabolic dunes has stabilised the dunes and stopped the movement of dunes and windblown sand. The trees have now grown to such an extent that it is extremely difficult to observe the parabolic dune morphology within the forest area.

Greenley (1919) describes sand blowing across bare rock and likens the scenery at Newborough to the Sahara Desert in Sudan. This landscape of bare rock and mobile dunes illustrated and described by Greenly has totally disappeared beneath the forest.

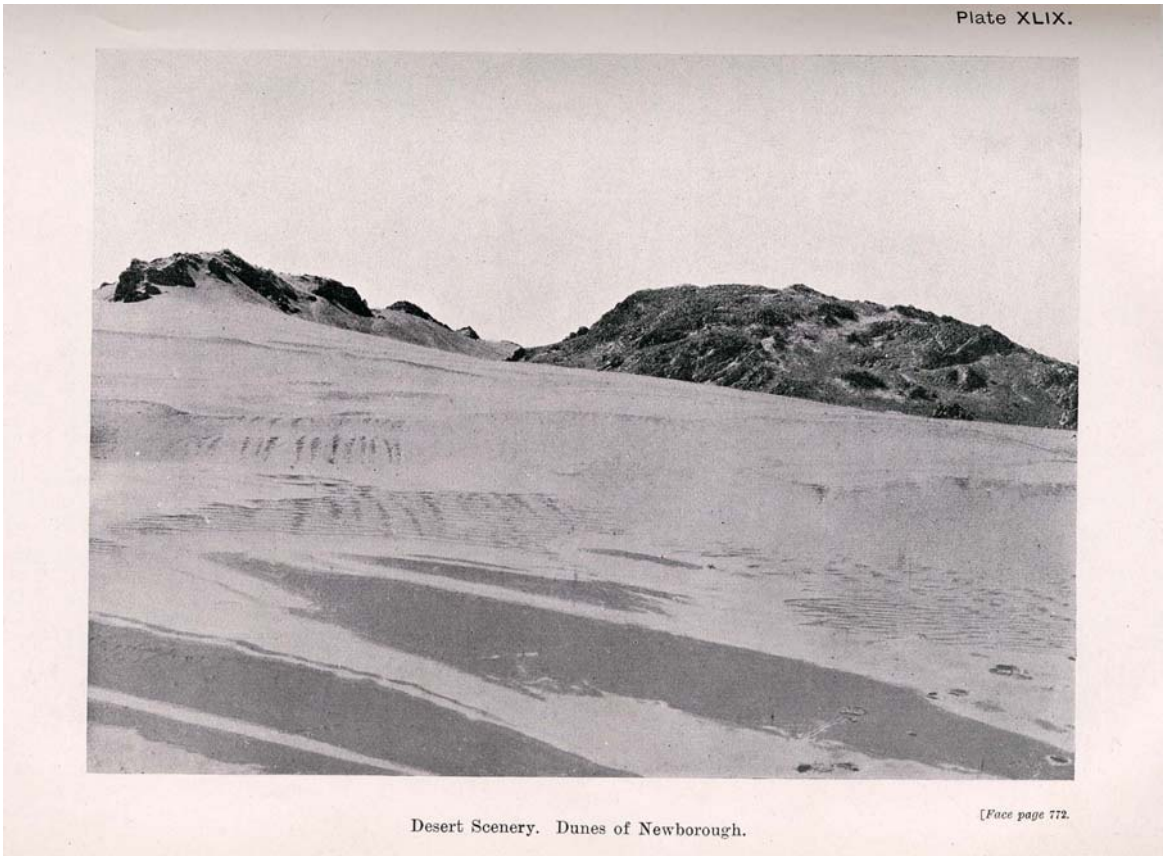

Figure 2 Photograph of wind blown sand piling up against the rock ridge from Greenly (1919) who compared Newborough to the desert of Sudan. This desert landscape of bare rock and shifting sand has been destroyed by the coniferous forest plantation at Newbough.

The growth of forest on dunes at Newborough has obscured the natural geomorphology, in addition, the plantations have prevented the natural processes of sand movement and dune migration on the rock ridge and a significant area of parabolic dunes.

In addition to the growth of the forest the vegetation cover in the open warren has also increased (Rhind et al. 2000) accompanied by the almost total loss of bare sand and mobile dune communities away from the beach. The growth of this vegetation has clearly restricted dune mobility and affected the geomorphology. The cause of increased vegetation within the open warren is partly blamed on a dramatic decrease in the rabbit population after Myxomatosis (Ranwell 1960). While more recent increases and changes in vegetation may also be a response to increased nutrients, especially nitrogen, from atmospheric pollution (Rhind et al. 2001).

1.5 The Effects of Forestry on Coastal Erosion

The forest has three direct impacts on coastal erosion at Newborough Warren: Reduction in wind shear, dune cliffing, and fallen branches.

1.5.1 Reduction in wind shear

A stand of trees on top of the dunes causes onshore winds to be deflected up over the trees reducing the wind shear at the level of the beach and the surface of the dunes (Figure 3A). A reduction in wind shear across the beach and dunes will reduce the transport of windblown sand from the beach to the dunes. In the short term this reduces the sand supply to dunes and can adversely affect sand dune formation and sand dune flora such as *Ammophila* which benefit from sand supply. A reduction in sand transport across the back-beach will also restrict the formation of embryonic shifting dunes and shifting dunes along the shoreline with *Ammophila arenaria*, two of the habitats listed in the SAC designation. In the longer term a reduction in the transport of wind blown sand from the beach can have more serious consequences for beach and dune erosion. Under normal fairweather conditions sand is blown from the beach into the dunes and adds to the foredune ridge (Figure 4A). This sand is then stored within the foredune ridge until it is released and blown inland by blowouts or is eroded during storms. In this respect the dunes act as a reservoir of sand that can be a source of sand to replenish the beach during storms (Figure 4B). If the dunes are not built up and resupplied during fair-weather conditions then the reservoir of sand becomes depleted and beach erosion is accelerated during storm events because the dunes are no longer able to withstand wave attack and there is no sand available to replenish the beach (Figure 4C). Removal of the forest, tree stumps and brush from the dunes will help to restore the natural exchange of sand between beach and dunes which serves to reduce the impact of storm erosion.

1.5.2 Dune cliffing

The second impact of the forestry at Newborough is to increase cliff formation when dunes are eroded because the root-plates of the trees binds the soil at the top of the dunes. With the root-plate binding the top of dune in position, the underlying unconsolidated dune sand can be eroded leaving a dangerous overhand and steep unstable cliff (Figure 3B and Figure 5). The dune cliffs are undesirable for two reasons. Firstly the undermined overhang at the top of the dune cliff is unstable and could cause an accident. The steep dune cliffs attract some children who like to jump down onto the sand slope underneath. This is potentially dangerous and could easily results in a broken limb. Secondly the steep dune cliff is not easily revegetated and without vegetation the bare sand surface is subject to increased erosion by wind and waves. To prevent dune cliffing it is essential that tree root-plates are removed from the foredune ridge. The removal of roots will also help increase natural sand movement and restore active sand transport within the dunes.

Figure 5
Tree root plates bind the sand leading to the formation of cliffs along the dune front when the beach and dunes are eroded. Dune cliffs like this are unstable. An unstable face could cause accidents and the steep unstable slope prevents plant colonisation hindering dune recovery.

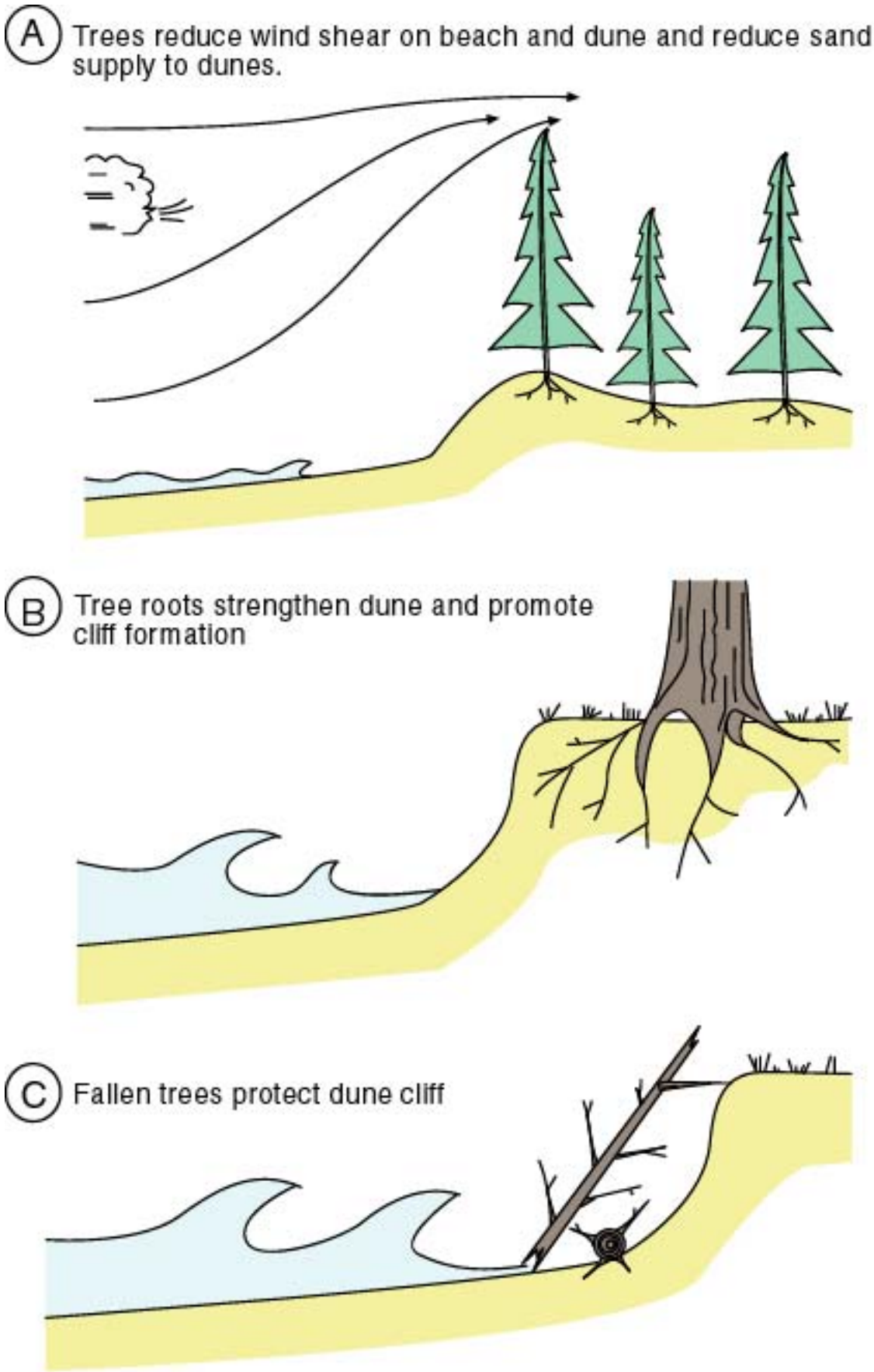

Figure 3 Impact of forestry on beach and dune processes

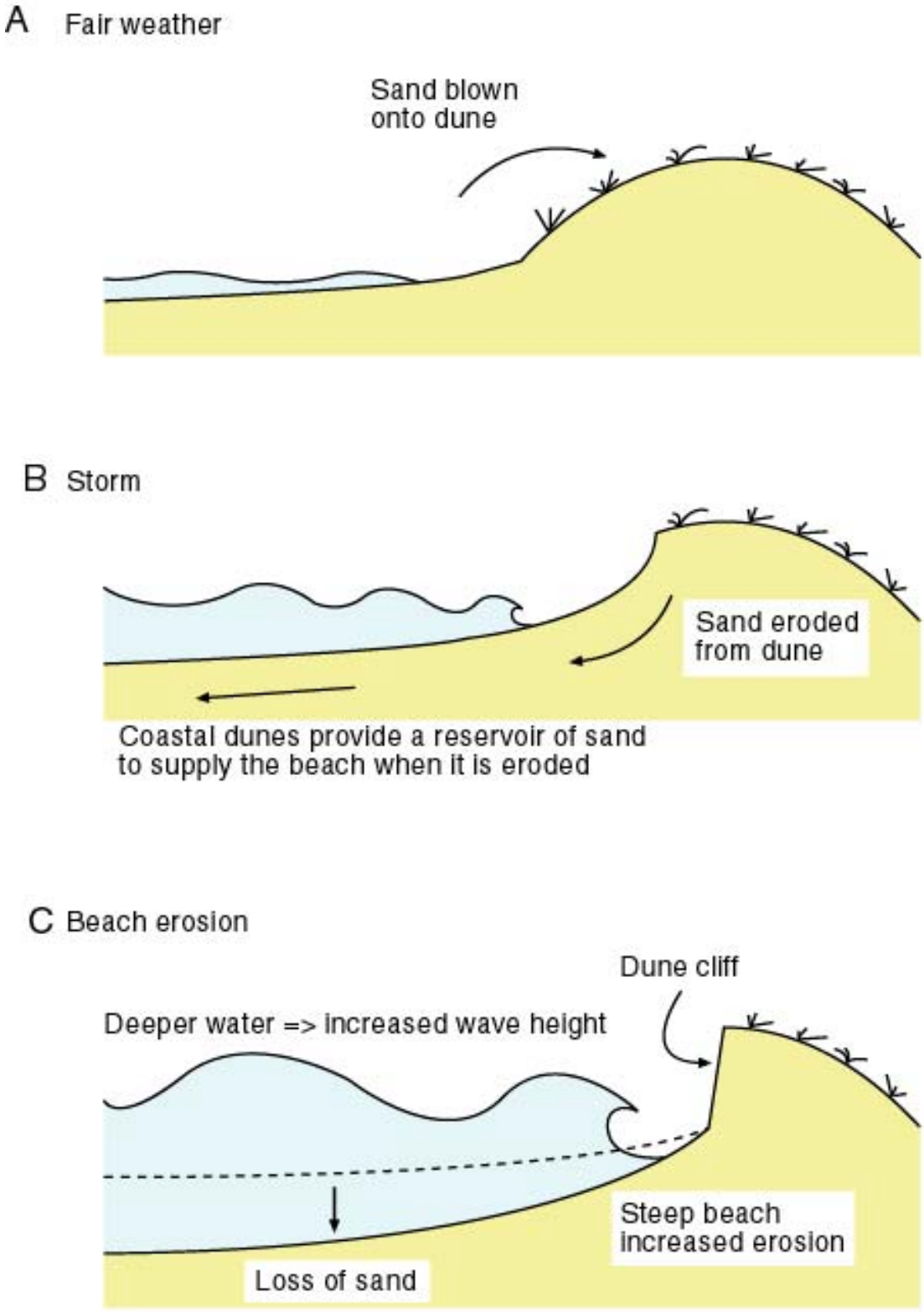

Figure 4 Exchange of sand between beach and dunes:
A During fairweather conditions sand is blown from beach to dunes,
B During storms sand is eroded form the dune front and rechrages beach,
C With further erosion and a lack of sand supply to the beach both beach and dunes can be eroded

1.5.3 Fallen trees and branches

Fallen trees and branches often lie along the foot of the dunes after storm events having been undermined during the storms and fallen onto the beach as the dunes are eroded (Figure 3C). The fallen trees and branches look unsightly and could be a hazard for visitors. As a results fallen branches and tree trunks are usually cleared from the beach. However, it has been noticed that a tangle of fallen branches and tree trunks at the foot of the dunes can help to protect the dunes against further wave attack and can act as an obstacle to trap wind blown sand. In this respect fallen trees and branches can act as roughness elements like rudimentary sand fences or brushwood helping to trap sand and initiate dune formation on the back beach.

1.6 Boreholes

As part of this study 7 boreholes were drilled at Newborough Warren, the objectives of the drilling were to determine the depth to bedrock beneath the Warren and the thickness of overlying sands and also to detect any heterogeneity within the sands which could affect the hydraulic conductivity of the sands. The results of the drilling is reported in Volume 4 of this report and summarised here. Three boreholes (NH1, NH2 and Borehole 3) were drilled with a portable flow-through auger that produced continuous core to a depth of 6.5m. Boreholes NH1 and NH2 both encountered thin organic layers within the sands which may be correlated. These boreholes did not find any evidence for significant permeability barriers or lateral changes within the sands and did not penetrate the full sand section. A water borehole and observation well with 6 inch diameter casing were installed close to the edge of the forestry. The water borehole was drilled to a depth of 12.8m and encountered a peat at a depth of 10m (1.77m OD) which appears to mark the base of the aeolian sands and to overlie estuarine sands. This was the deepest drilled in this study and had to be abandoned due to running sands and did not reach basement. The only borehole that reached basement was the Forest Borehole (FBH) which encountered basement at a depth of 7m (3.03m OD). The borehole is located around 180m inland from the back of the beach near profile 18 and shows bedrock at an elevation of 3.03m which is above mean high water (2.11m OD) and above highest astronomical tides (2.8m OD) and close to the level of the base of the dunes at Profile 18. If erosion of the beach and dunes at Llanddwyn beach continues than the shoreface will intersect bedrock at less than 180m inland which should prevent or reduce further coastal erosion.

1.7 Geophysics

Two geophysical techniques, Ground Penetrating Radar (GPR) and Seismic refraction survey have been used in this study to investigate the depth to basement, thickness of aeolian sand and shallow stratigraphy at Newborough Warren. The results of the geophysical surveys are presented in volume 3 and summarised here. The GPR survey successfully imaged the depth to bedrock on the rock ridge and along the beach near the residents car park down to depths of 5 to 6m. The GPR also imaged the water table beneath dune ridges, sedimentary structures and shallow stratigraphy within the dune sands down to a depth of around 5m. The GPR profile across the warren shows that the stratigraphic horizons within the sands are often continuous for 100s of meters with local development of trough shaped scours and sets of cross-stratification

from dune bedforms. The GPR was not able to image the depth to basement at greater than 6m and it is safe to assume that there is more than 6m of sand beneath most of the warren. This is confirmed by the borehole results. The results of the seismic refraction survey were disappointing because the seismic was unable to determine the depth to basement within the warren. However, seismic surveys along the beach close to the visitors car park and at Abermenia Point indicate that the depth to basement and sand thickness is up to 20 or 30m.

1.8 Water table

One of the major concerns for management of Newborough Warren is winter flooding of the wet interdune slacks. It was noticed that the frequency and depth of flooding of interdune slacks had decreased and it was suspected that this was due to a reduction in the elevation of the water table at Newborough Warren. A reduction in the water table could be due to increased interception and increased evapotranspiration within the forest area leading to a reduction in groundwater recharge within the open warren. In a study of the vegetation and environment of afforested sand dunes at Newborough Warren Hill and Wallace (1989) noted that planted trees had had two major effects on the soil. They have lowered the water table and they have stabilised the dunes (Hill and Wallace 1989, p.263). They recorded that on unplanted ground within the forest, the major effects were lowering of the water table and they observed that many slacks which had not been planted with trees because they were too wet are now dry. There is thus clear evidence to suggest that the forest has caused a fall in the water table in the afforested area of the warren but the question remains as to how much or how far did this effect extend into the open warren. The results of an investigation into the hydrogeology of Newborough Warren are presented in volume 5.

The hydrogeological model generated using MODFLOW has been used to investigate the effects of land use change on the groundwater levels within the warren by changing recharge values to simulate changes in vegetation from forest to dune grassland. It should be noted that, in addition to and coeval with the forest growth, the vegetation cover within the open warren has increased. The model indicates that the effect of removing all of the forest is to raise groundwater levels within the warren. The model indicates that the potential impact of removing forestry is spatially variable. Removal of forest closest to the coast has the least impact because this area does not contribute to recharge within the open warren. Removing 50 Ha of forest from the edge of the forest closest to the warren is shown to raise the water table by 10cm or less. The model indicates that removing 50 Ha of forest from higher ground to the north has the greatest impact. This is because a greater proportion of recharge in this area flows down-slope towards the open warren and the higher topography in this area creates a significant hydraulic gradient increasing the groundwater flux into the warren.

It should be noted that the model is a non-unique solution and there are a number of uncertainties associated with the model. The uncertainties include: The amount of interception and evapotranspiration from dune and interdune vegetation, the depth to basement and thickness of the sands at Newborough Warren, the contribution of groundwater recharge from the basement rocks and the valley of the Afon Braint and the effect of dry cells within the model. The

evapotranspiration from dune vegetation is poorly constrained and recharge values calculated from meterorological data had to be adjusted to make the model fit the target values. The hydraulic conductivity of the dune sands was initially calculated from grainsize analysis, field and laboratory measurements which showed reasonable agreement but the values within the model were reduced to fit the target values. In order to meet target values within the model the recharge values and conductivity values were reduced. One possible explanation for the difference between the calculated recharge and the recharge values required within the model is that there is additional recharge entering the warren from groundwater flow within the rock ridge and beneath the valley of the Afon Braint. Within the model the landward side of the warren is assigned a no flow boundary. In reality these boundaries may be hydrologically open allowing water to flow in and out of the dune sands.

1.9 Conclusions and Recommendations

The most noticeable effect of the forestry at Newborough Warren is the loss of a landscape of mobile parabolic dunes and active sand dunes moving across bare rock. These losses are due to stabilisation of previously mobile dunes during the planting and growth of the trees. The subsequent growth of the trees has largely obscured the parabolic dune morphology. Removal of the forest, tree stumps and brush from the rock ridge and areas behind the dune front will help to restore natural processes and geomorphology at Newborough Warren.

The trees have also had a detrimental effect on the dune front because the tree roots promote dune cliffing by binding the sand. A high stand of trees close to the dune front will also cause a reduction in wind shear on the beach and dune front reducing the transport of wind blown sand from beach to dunes. In addition, the reduction of sand transport form beach to dunes will reduce the ability of dunes to be “repaired” in between storm events increasing dune erosion in the longer term. Removal of the forest, tree stumps and brush from areas behind the dune front will help to restore natural processes and geomorphology at Newborough Warren.

Fallen trees and branches at the foot of the dunes look unsightly and could be a hazard for visitors. However, they can also act as a rudimentary sand fence helping to protect the dune cliff, trap sand an initialise dune formation.

The creation of a mobile dune system should be encouraged because this will restore the natural geomorphological processes. In addition, mobile dunes provide new areas of bare sand for vegetation colonisation maintaining a natural succession of sand dune vegetation. Indeed, many sand dune plants benefit from active sand deposition and deflation in interdune areas is responsible for the creation of wet slacks which are an important component of the natural habitats at Newborough Warren.

The increase in vegetation in the open warren is also a cause for concern because this has also decreased dune mobility and adversely affected the geomorphology. The causes of the increase in vegetation and the possible effects of nitrogen pollution require further investigation. In addition the effects of

increased vegetation on evapotranspiration and groundwater levels within the open warren requires further research.

Removal of the forest, tree stumps and brush from the rock ridge and areas behind the dune front will help to restore natural processes and geomorphology at Newborough Warren.

In order to develop a better hydrogeological model of Newborough Warren there are several areas which require additional research. The thickness of the sand is still poorly constrained and further geophysics and or drilling would be required to constrain the depth to basement and sand thickness. The amount of interception by and evapotranspiration from dune and interdune vegetation is poorly constrained and requires additional research. Within the MODFLOW model developed for this study the hydraulic conductivity had to be reduced to match the water level observations. The water borehole installed as part of this project could be used to conduct a pump test and calculate hydraulic conductivity in the field. A model should be constructed with hydrologically open boundaries along the rock ridge and improved estimates of interception, recharge, evapotranspiration and aquifer properties.

Despite the problems with the existing model it does show that removing areas of forest along the high ground know as the rock ridge will result in increased groundwater recharge and raise the water table within the warren.

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