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An Inventory of Wetland Plant Communities in Burren National Park, Ireland

Natural Resource Report NPS/KLMN/NRR—2015/937



ON THE COVER
Vegetation zonation at Skaghard Lough, Burren National Park, 2008.

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Contents

Page

Figures v

Tables viii

Acknowledgements ix

Executive Summary x

Introduction 11

Wetlands Defined 11

Types of Wetlands 11

Wetland Phytosociology of the Burren Region 13

Study Area 13

Inventory Objectives 14

Methods 15

Site Selection 15

Field Data Collection 15

Floristic Sampling 16

Environmental Sampling 16

Figure 5a-c. Plot vegetation photos: a) Planview of plot, b) downtransect view, c) uptransect view.Geographic Data Preparation 20

Floristic Analyses 21

Identification of Mapping Units 22

Image Acquisition and Classification 22

Analyses of Floristic Diversity 22

Analyses of Livestock Influences 23

Results 25

Biomass Estimation 25

Classification of Wetland Vegetation Communities 25

Relationships between Vegetation and Environment 30

Image Classification 33

Wetland Community Types of the Burren National Park 34

A. Seasonally-Flooded, Middle Wetland Communities 44

Contents (continued)

Page

A. Semipermanently- and Permanently-Flooded, Lower Wetland Communities 60

Major Wetland Complexes of the Burren National Park 72

Patterns of Floristic Diversity 96

Patterns of Livestock Use and Impact 99

Discussion 103

Study Limitations 103

Interpreting the Wetland Landscape of Burren National Park 103

Wetland Community Types of Burren National Park 104

Biodiversity and Conservation Significance of Burren National Park Wetlands 106

Threats to Wetland Biodiversity 108

Conclusions and Implications for Management 108

Literature Cited 111

Figures

Page

Figure 1. Insert: Location of study area in Republic of Ireland 14

Figure 2. Overview map showing location of the centripetal transects in Burren National Park wetland complexes. 16

Figure 3. Diagram of livestock disturbance sampling estimate in relevé 17

Figure 4 a-c. a) Biomass meter (calibrated meter stick) viewed a) horizontally, and b) vertically. c) Clipped vegetation biomass sample being dried to a constant weight in the laboratory, d) soil sample collected with screw auger. 19

Figure 5a-c. Plot vegetation photos 20

Figure 6. Measured above ground dry weight (g/m^2) of plant material as a function of Biomass Index 25

Figure 7. Dendrogram from hierarchical cluster analysis with community types/mapping units overlaid. 27

Figure 8. Histogram of most frequently chosen environmental variables out of 20 possible models selected by the BIOENV procedure in PRIMER. 30

Figure 9. Nonmetric Multidimensional Scaling (NMS) ordination illustrating the wetland vegetation communities types and all environmental variables with a Pearsons correlation coefficient greater than 0.3 with ordination axes. 32

Figure 10. Image classification. 33

Figure 11. Overview of major wetland community types of the Skaghard-Travaun-Coolorta-AughrimTurlough Complex. 34

Figure 12. Raised Bog community type in Burren National Park 36

Figure 13. Common vascular plant species of the Raised Bog community type in Burren National Park. 37

Figure 14. Distribution of the Raised Bog Community Type (Map Unit 1) in sampled wetlands of Burren National Park. 38

Figure 15. Overview and common vascular plant species of the Limestone Shrubland community type in Burren National Park 40

Figure 16. Overview and common vascular plants of the Limestone Meadow community type 42

Figure 17. Distribution of the sparsely vegetated Limestone community types (Map Unit 2) in sampled wetlands of Burren National Park. 43

Figure 18. View of sampling relevés in Carnation Sedge Fen community types in a) ungrazed, and b) grazed conditions 45

Figures (continued)

Page

Figure 19. Common plant species of the Carnation Sedge community type in Burren National Park 46

Figure 20. Distribution of the Carnation Sedge Fen community type (Map Unit 3) in sampled wetlands of Burren National Park..... 47

Figure 21. Overview of Black Bogrush community type 49

Figure 22. Common wetland plants of the Black Bogrush community type 50

Figure 23. Distribution of the Black Bogrush Fen community type (Map Unit 4) in sampled wetlands of Burren National Park..... 51

Figure 24. Overviews of sample relevés in relatively a) ungrazed and b) grazed, poached conditions. 53

Figure 25. Common vascular plants of the Wet Sedge Fen and Flush community type 54

Figure 26. Distribution of the Wet Sedge Fen and Flush community type (Map Unit 5) in sampled wetlands of Burren National Park..... 55

Figure 27. Overviews of sampling relevés in Turlough Floor community type. 57

Figure 28. Characteristic vascular plants of Turlough Floor community type 58

Figure 29. Distribution of the Turlough Floor community type (Map Unit 6) in sampled wetlands of Burren National Park. 59

Figure 30. Views of Sawsedge Fen community type..... 61

Figure 31. Characteristic plants of the Sawsedge Fen community type 62

Figure 32. Distribution of the Sawsedge Fen community type (Map Unit 7) in sampled wetlands of Burren National Park. 63

Figure 33. Views of Bulrush-Common Reed Reedswamp community type 65

Figure 34. Views of Dense Bulrush-Common Reed Reedswamp community type in Lough Awaddy..... 66

Figure 35. Distribution of the Bulrush-Common Reed Reedswamp community type (Map Unit 8) in sampled wetlands of Burren National Park. 67

Figure 36. Views of Sparsely Vegetated Marl Flat community type..... 69

Figure 37. Context and characteristic vascular plants of the Turlough Floor community type..... 70

Figure 38. Distribution of the Sparsely Vegetated Marl Flat community type (Map Unit 9) in sampled wetlands of Burren National Park. 71

Figure 39. Major wetland complexes of Burren National Park. 72

Figures (continued)

Page

Figure 40 a.) Ballyeighter Peatland complex, b) distribution of mapping units in the Ballyeighter Peatland complex. 74

Figure 41. Skaghard-Coolorta-Trauvaun-Aughrim wetland complex 76

Figure 42 a.) Skaghard Lough wetland subcomplex, b) distribution of mapping units in the Skaghard Lough subcomplex. 77

Figure 43 a.) Coolorta-Travaun Area of Skaghard-Coolorta-Travaun-Aughrim Wetland complex, b) distribution of mapping units in the Coolorta-Travaun area. 79

Figure 44 a.) Lough Aughrim area of Skaghard-Coolorta-Travaun-Aughrim Wetland complex, b) distribution of mapping units in the Lough Aughrim area. 80

Figure 45. Lough Awaddy: a) Lough Awaddy ponds. Note zonation from aquatic to wet sedge to common reed vegetation, b) View into largest pond illustrating floating and submergent aquatic vegetation. 82

Figure 46. Aughrim Ponds. 83

Figure 47. Lough Awaddy: a) overview of Lough Awaddy, b) distribution of mapping units in wetland. 84

Figure 48. Aughrim Ponds: a) overview of Aughrim Ponds, b) distribution of mapping units in Aughrim Ponds 85

Figure 49. Oblique view of Coolreash Wetland Complex 87

Figure 50. a.) overview of Coolreash Wetland Complex, b) distribution of mapping units in the Coolreash Wetland complex. 88

Figure 51. Water levels in Lough Gealáin in spring 2008: a) April 24th, b) June 19th. Much of Lough is less than 2m in depth. 90

Figure 52. Fens in the Lough Gealáin Wetland Complex 91

Figure 53. Lough Gealáin Wetland Complex 92

Figure 54. Views of Knockanroe Wetland Complex 94

Figure 55. Views of Knockanroe Turlough Complex 95

Figure 56. Species richness univariate scatterplots (species / 4m^2 relevé) 96

Figure 57. Regression tree illustrating conditions of high and low vascular plant species richness in Burren National Park wetlands 98

Figure 58. Mean (+ s.e.) levels of livestock impact in each of the major wetland community types of BNP 100

Figure 59. Mean (+ s.e.) browsing and poaching index score in the three relative elevations sampled (n= 32 per elevation) class. 101

Tables

Page

Table 1. Comparison of mapping units and vegetation types with Curtin (2009) groups and recognized phytosociological and habitat classes. 28

Table 2. Wetland composition of Ballyeighter peatland complex. 73

Table 3. Wetland composition of Skaghard Lough subcomplex of the Skaghard-Coolorta-Trauvaun-Aughrim wetland complex. 75

Table 4. Wetland composition the Coolorta-Travaun-Aughrim subcomplex of the Skaghard-Coolorta-Trauvaun-Aughrim wetland complex. 78

Table 5. Wetland composition of Lough Awaddy and Aughrim Ponds complexes. 81

Table 6. Wetland composition of the Coolreash Fen complex. 86

Table 7. Wetland composition of the Lough Gealáin wetland complex. 89

Table 8. Wetland composition of the Lough Gealáin wetland complex. 93

Table 9. Coefficients of determination and statistical significance of component factors in best model selected by stepwise multiple regression analysis. 97

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Executive Summary

This report describes results of a collaborative floristic inventory effort based on fieldwork conducted in spring of 2008 by Dr. Daniel Sarr from the Klamath Network of the National Park Service, and John Curtin and Dr. Micheline Sheehy Skeffington of Botany Department, National University of Ireland, Galway. Lorin Groshong of Southern Oregon University assisted with subsequent image classification and map development. The report is intended to provide an overview of the major community types of the park's wetlands, to provide a preliminary wetland map for the park, and to discuss the patterns and factors affecting wetland plant diversity in the park wetlands. In spring 2008, we conducted a floristic inventory of the major wetland basins in Burren National Park to describe and map the major wetland vegetation types and to explore patterns of plant species diversity. At each wetland, we sampled vegetation composition, soils, and hydrological data along centripetal transects from the wetland edge to interior and conducted repeat photography at several locations to document seasonal flooding dynamics. A total of 96 relevé samples were collected in 32 wetlands. Floristic and imagery data were classified in parallel then merged and summarized to provide an overview of the major wetland types in the park, and their relationships to the environment. Floristic classification was conducted with hierarchical cluster analysis and multidimensional scaling. Supervised image classification was conducted with aid of ERDAS Imagine software. Additional analyses explored the primary environmental factors associated with vascular plant species richness and quantified levels of livestock utilization and impact across community types.

A total of nine mappable vegetation types were recognized from the inventory and classification, and an open water type. The units include two temporarily flooded upper wetland community types: *Raised Bog*, and *Limestone*, which consisted of two subtypes, *Limestone Shrubland*, and *Limestone Meadow*. Seasonally flooded types at intermediate elevations in the wetlands included *Carnation Sedge Fen*, *Black Bogrush Fen*, *Wet Sedge Fen and Flush*, and *Turlough Floor Meadow*. At the lowest relative elevations in the bottoms of the wetland basins, we recognized semipermanently and permanently flooded *Sawsedge Fen*, *Bulrush-Common Reed Reedswamp*, and *Sparsely Vegetated Marl Flat*. Descriptions of each type are provided along with statistical summaries of biomass, diversity, and environmental variables, maps showing the distributions in the park, and images of selected species.

Vascular plant diversity declined from the upper relative elevations towards the floors of the wetland basins. This decline was primarily across wetland types, with a transition from generalist upland species toward aquatic specialists with increasing depth and duration of flooding in the wetlands. As has been noted elsewhere in wetland studies, species richness was greatest in low to moderate biomass relevés that were at relatively high elevations in the wetland basins. In the limestone types, the high diversity and low biomass appeared to be controlled by the rocky, discontinuous soils, which prevent any one plant form dominating. In the densely vegetated fen types, particularly the Carnation Sedge community type, low biomass areas, which were often grazed, showed high vascular plant species richness. Further work addressing other dimensions of diversity (e.g., wetland invertebrates) may be helpful for developing a more complete understanding of the patterns and drivers of native biodiversity in Burren National Park wetlands.

Introduction

Wetlands are major attractions and ecologically significant features of the Burren National Park, Ireland (Figure 1), and knowledge about wetland ecosystems is especially valuable in national parks and other natural areas where nature conservation and environmental education are primary concerns. These distinctive ecosystems add to the biological diversity of the park and to the richness of the visitor experience. This report describes results of a collaborative floristic inventory effort conducted in spring of 2008 by Dr. Daniel Sarr from the Klamath Network of the National Park Service and John Curtin and Dr. Micheline Sheehy Skeffington of Botany Department, National University of Ireland, Galway. Lorin Groshong of Southern Oregon University assisted with subsequent image classification and map development. The report is intended to provide an overview of the major community types of the park's wetlands, to provide a preliminary wetland map for the park, and to discuss the factors affecting wetland plant diversity in the park wetlands.

Wetlands Defined

Wetlands are often islands of unique biodiversity in landscapes. Although many definitions exist, a general definition from the Convention on Wetlands in Ramsar, Iran, 1971 describes wetlands as "areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide are less than six meters." More succinctly, the term 'wetland' implies an area where water and land are both obviously present, as opposed to terrestrial or deep open water habitats, such as seas and lakes (Otte 2003). Generally, wetlands are evidenced by distinctive vegetation, soils, and hydrology, and precise legal wetland definitions have been developed in some countries, such as the United States (Mitsch and Gosselink 2000).

Types of Wetlands

Wetlands are as variable in form and function as the landscapes in which they occur. Variation in the timing and duration of water governs the types of wetlands seen and the species that occur in them. The seasonally or permanently saturated conditions that often occur in wetlands create radically different features for plant and animal life. Oxygen, essential for metabolism of most organisms, diffuses 10,000 times slower through water than air; therefore, saturated soils are anaerobic, stressful environments (Otte 2003). This gives rise to the accumulation of organic matter as peat. The absence of oxygen also creates uniquely reduced conditions in wetland soils. In saturated soils, oxidation-reduction potential, or redox potential, indicates the occurrence and intensity of anaerobic conditions and provides an integrative measure of physical and biological conditions in subsurface environments (Mitch and Gosselink 2000). Variability in flooding is important as is its timing. Permanently saturated areas, such as fens and lake margins, often have different species than more variable systems like turloughs (Ivimey-Cook and Proctor 1966, O'Connell et al. 1984). While soils are often saturated for weeks in winter in many areas of Ireland, the low temperatures and short day lengths lower biological activity and, therefore, oxygen demand in the dormant season. Generally, only areas that are reliably saturated during the growing season are considered true wetlands.

In wet regions such as Ireland and northwest Europe in general, the biogeochemistry of wetlands is particularly vital in controlling wetland plant composition (Wheeler and Proctor 2000). Distinctive wetlands often occur because of differences in the parent material or sources of water flowing into the wetland creating different chemical profiles. Although many areas of western Ireland are wet enough to support extensive boglands over the landscape, these wetlands are far more extensive in areas where the bedrock weathers to acidic soils, such as the quartzites and granite of Connemara. In these areas, *Sphagnum* moss species flourish. These sponge-like mosses greatly increase retention of moisture and further acidify the soil, allowing extensive boglands to develop. On limestone parent materials, especially the exposed bedrock areas of the Burren and environs, where calcium carbonate is available in abundance, buffering capacity is high, *Sphagnum* does not grow, and bogs only develop in exceptional circumstances.

The West of Ireland is one of the world's richest wetland landscapes. Many parts of the region are cloaked in reedswamps, bogs, fens, and turloughs, with complex mosaics created by varied climate, topography, and geology (Otte 2003). Generally, Irish wetland types can be differentiated by the depth, duration, reliability of flooding, and chemistry of the water within them (O'Connell et al. 1984). Reedswamps or marshes occur in areas of deep standing water in the growing season and typically less peaty soils. These sites are most common around permanent lakes and depressions within larger shallower basins.

As in other cool, hyperhumid regions, western Ireland is especially rich in peatlands. In such regions, where the production of plant material outpaces its decomposition, peat forms and can transform the landscape and its chemical character. Peatlands are typically saturated with moisture during much of the growing season but do not have deep standing water. Wheeler and Proctor (2000) provide an overview of the history of study of peatland vegetation in Northwest Europe, and point out that the floristic composition is often determined by the gradient in acidity, the availability of the limiting nutrients nitrogen and phosphorus, and the water level. The most important division ecologically is between bogs and fens. Bogs typically have low pH (generally < 5), low Ca^{2+}, Cl^- and $SO4^-$ as the dominant anions present, with vegetation dominated by *Sphagnum* mosses, heath species and calcifuge members of the family Cyperacae (Proctor 2010). Fens, in contrast, have higher pH (usually > 6.0), high Ca^{2+} and HCO_3^-, and many herbs and brown mosses. Wheeler and Proctor (2000) emphasize that the distinction between bog and fen is not abrupt, and actual wetlands may have intermediate characters. In fact, they suggest that poor fens often have more chemical and floristic overlap with bogs than rich fens. General classifications of peatland vegetation types have been summarized for Ireland by O'Connell (1984) and Feehan and O'Donovan (1996).

Turloughs are groundwater-dependent wetlands that occur in limestone depressions mainly in the limestone karst landscape of the west of Ireland (Sheehy Skeffington et al. 2006). The flooding regime of turloughs is linked to precipitation patterns, and flooding can occur at any time of the year during high rainfall events. However, flooding occurs between October and April in most years (Coxon 1987, Moran et al. 2008). Turloughs are traditionally important summer grazing pastures and the substrate and grazing management are also important factors in determining species distribution (Goodwillie 2003). The turloughs of Burren National Park, particularly Lough Gealáin,

have been featured in a number of studies of Burren wetlands (Goodwillie 2003, Proctor 2010), but an inventory and map of park wetlands has not been prepared.

Wetland Phytosociology of the Burren Region

The Burren region in County Clare is a broad glaciated plateau of Carboniferous limestone bedrock that faces the Atlantic on the southern shore of Galway Bay (Figure 1). Due to its unique geologic, climatic, and human management history, the Burren is a center of floristic diversity and rarity in northwest Europe (Ivimey-Cook and Proctor 1966, Otte 2003). The spectacular plant diversity of the limestone pavements in the Burren is world-renowned, but the wetlands have to date received less intense interest by scientists and the public. Nonetheless, a rich variety of wetland plant communities have been described in the Burren, including distinctive marl, turlough, fen, bog, and reedswamp communities (Praeger 1934, Webb 1962, Ivimey-Cook and Proctor 1966, and O'Connell et al. 1984). According to Ivimey-Cook and Proctor (1966), there are seven classes describing Burren wetlands, including *Plantaginetea majoris* (turlough vegetation), *Phragmitetea* (reedswamps), *Litorelletea* (land pond margin vegetation), *Scheuchzerio-Caricetea fuscae* (bog hollow and fen), *Oxycocco-Sphagnetea* (wet heath and bog hummock), *Montio-Cardaminetea* (calcareous spring) and *Molinio-Arrhenatheretea* (wet meadow). O'Connell et al. 1984 and Ó Críodáin and Doyle (1994, 1997) have provided further refinements to this seminal work in recent years.

Study Area

The Burren National Park is located near the southeastern edge of the Burren, where the plateau gives way to lowlands, and it contains many examples of the unique geologic features and wetlands of the region, particularly turloughs. The park contains a large portion of the east Burren wetland complex, which drains primarily into the Fergus River Basin, and secondarily (Lough Bunny) which drains underground into the Kinvarra Catchment (Proctor 2010). The complex hydrogeology of the region creates one of the finest mosaics of wetland habitats in Ireland, with permanent lakes, turloughs, bog, and fens occurring in close proximity. At present, there is no inventory of the wetlands of the park. However, other regional studies have provided some details about the regional wetlands, particularly the turloughs (Goodwillie 2003, Sheehy Skeffington et al. 2006). The recent work by Proctor (2010) is an especially welcome synthesis of the hydrology, land use, and ecology of Burren wetlands.

As an anthropic landscape in the midst of an active agricultural region, Burren National Park is subject to livestock grazing by cattle and horses and by feral goats. The hand of humans has shaped the Burren since upper Neolithic times, and the grazing regimes of the region have been in place in one form or another for centuries (Watts 1984, O'Rourke 2005). Generally, hardy breeds of cattle were driven onto the limestone uplands in winter, where they grazed on the calcium rich upland pastures (Dunford 2002). The animals were lean, but with hearty frames well-suited to subsequent fattening on the low land pastures. Recent changes in cattle breed and shifts from wide-ranging steers to cow/calf pairs (suckler cows) has changed the system in recent years (Bohnsack and Carrucan 1999). Hazel encroachment in the uplands is considered a result of these changes (Dunford 2002), but the effects of grazing changes upon the wetlands of the park are presently unknown.

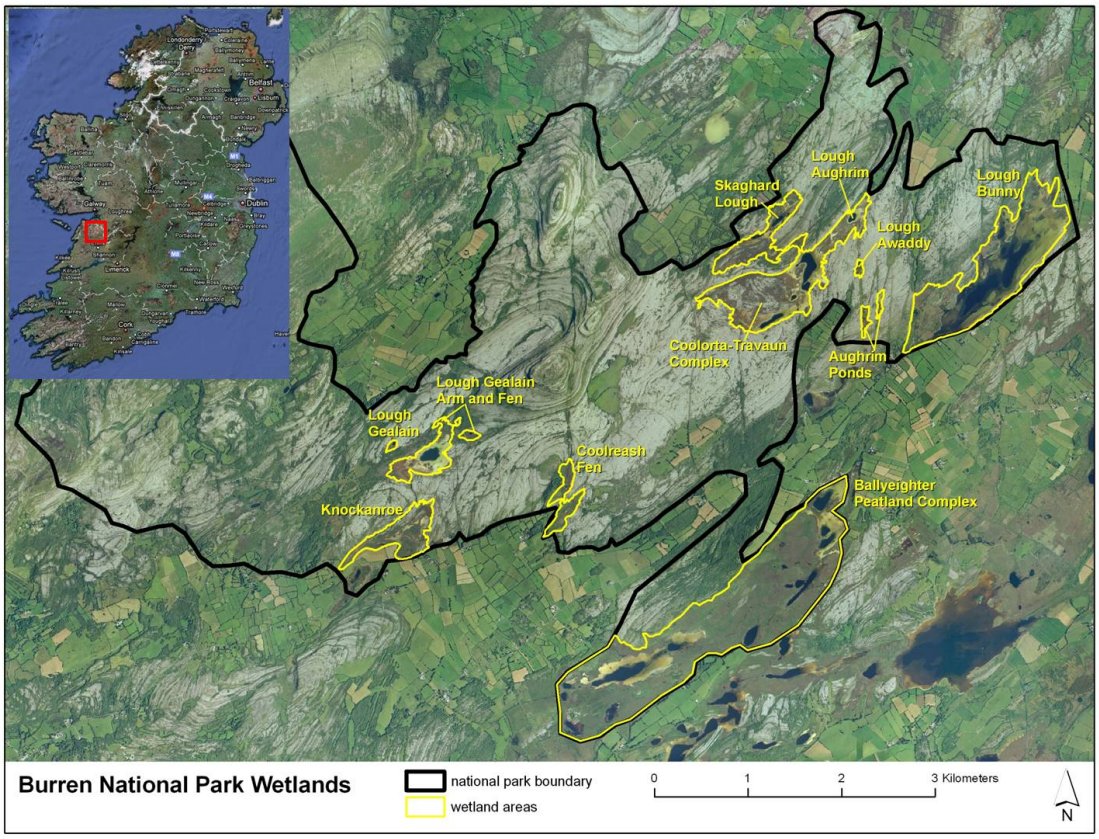


Figure 1. Insert: Location of study area in Republic of Ireland. Burren National Park, with major wetland complexes in park labeled.

In spring 2008, we met with the Emma Glanville, Seamus Hassett, and Tim O'Connell of the National Parks and Wildlife Service to discuss collaborative wetland research in the Burren National Park. At the meeting, it was decided that a broad wetland inventory would be a useful addition to the park's resource management knowledge, and possibly also of interest for interpretive and educational programs. We sought to build upon Dr. Michael Proctor's seminal work in the Burren in the 1950s, which he was hoping to publish as a monograph (published subsequently as Proctor 2010). We intended that our efforts complement and update the fundamental findings from his nearly 50 year old study in a specific region of the park. Although an increasing amount of research has focused on Irish wetlands, and the Burren in recent years (e.g., O'Connell et al. 1984; Ó Críodáin and Doyle 1994, 1997; Sheehy Skeffington et al. 2006; Regan 2007), site specific knowledge about the wetlands of the Burren National Park is still needed to aid park management and interpretation.

Inventory Objectives

1. Sample the vegetation of major wetland complexes of the Burren National Park.
2. Classify wetland vegetation and provide descriptions for park managers.
3. Provide a preliminary wetland vegetation type map for the Burren National Park.
4. Quantify the area and extent of the major wetland types in the Burren National Park.
5. Analyze floristic diversity as it relates to vegetative, environmental conditions, and livestock use.

Methods

Site Selection

Prior to the inventory, we met with park staff to discuss possible survey options for the park. We obtained a copy of the most recent aerial photograph of the park and region from the Irish Ordnance Survey, which provided a clear overview of the major wetlands complexes in the park. We determined that available time and resources would allow a maximum of 120 relevés for the field inventory. Target sample sizes for each wetland complex were apportioned from this maximum total based on the square root of the wetland complex area as well as the complexity in plant communities visible in the aerial photograph. All relevés were sampled in centripetal transects that ran from just inside the high water flood mark (as evidenced by flotsam and shoreline moss layers) towards the center of the wetland. Each transect had three relevés, selected to sample high, medium, and low sites along the topographic moisture gradient.

Field Data Collection

Vegetation and environmental variables were collected between May 20 and June 25, 2008 at 32 centripetal transects at 14 wetlands sites distributed throughout the park. At each wetland, we collected relevé data from 2 m x 2 m quadrats distributed along a topographic gradient from (usually) the landward edge of the wetland towards its center. The length of the transect and inter-relevé distances were based on the length of the topographic gradient. The transect was stratified into three zones, each composing a third of the total length, and relevés were placed a random distance into each zone. Although general transect locations were selected subjectively, we attempted to decrease obvious bias by randomly jiggering the landward edge of the transect by 20 meters from the target transect location. Random jiggering involved offsetting the start point a random direction (left or right) and distance (0-20m) from a subjectively selected starting point. Deep water habitats (sites with over 1 m of standing water at the time of sampling) were not sampled.

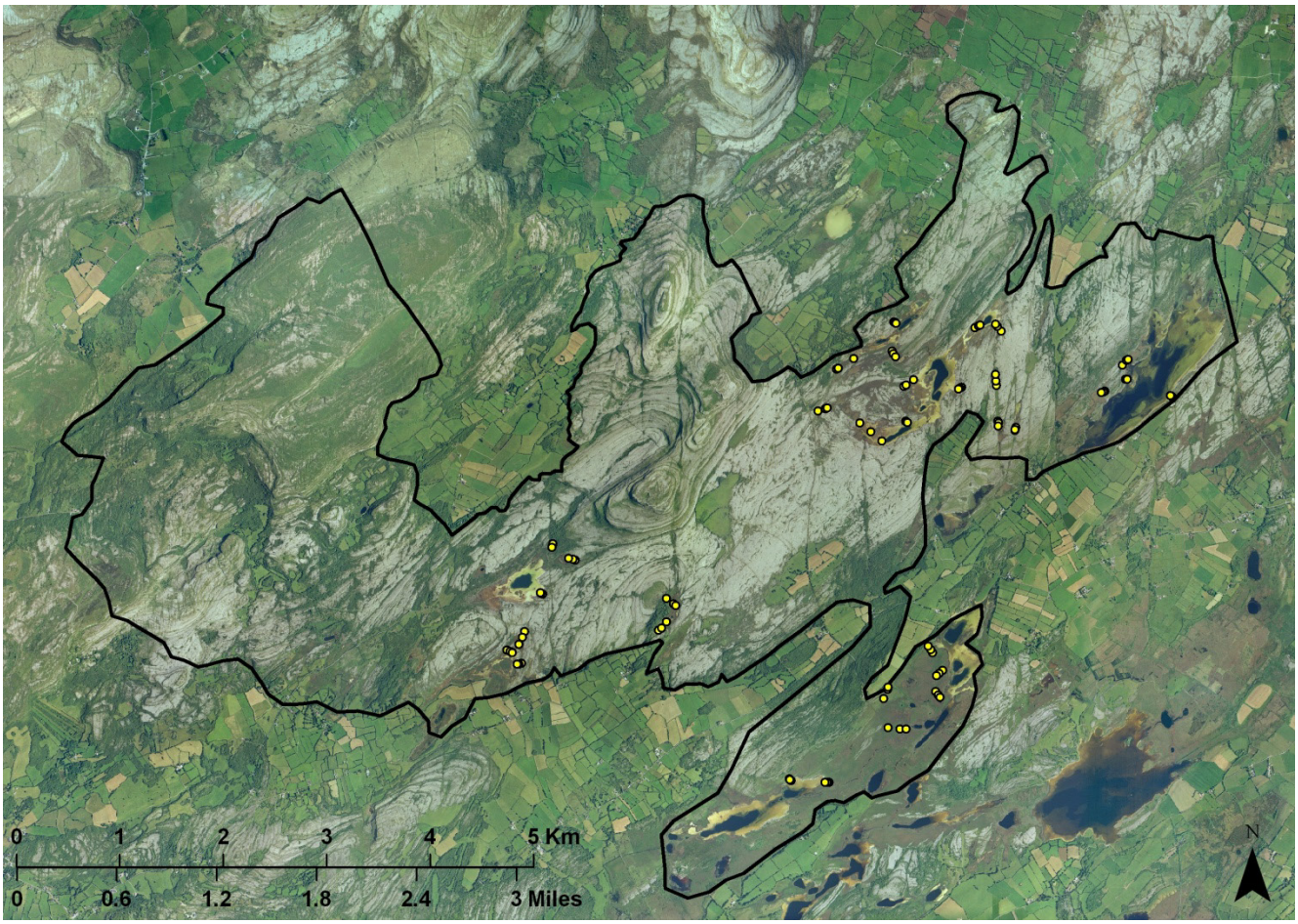


Figure 2. Overview map showing location of the centripetal transects in Burren National Park wetland complexes. Yellow dots indicate position (using GPS) of sample relevés.

Floristic Sampling

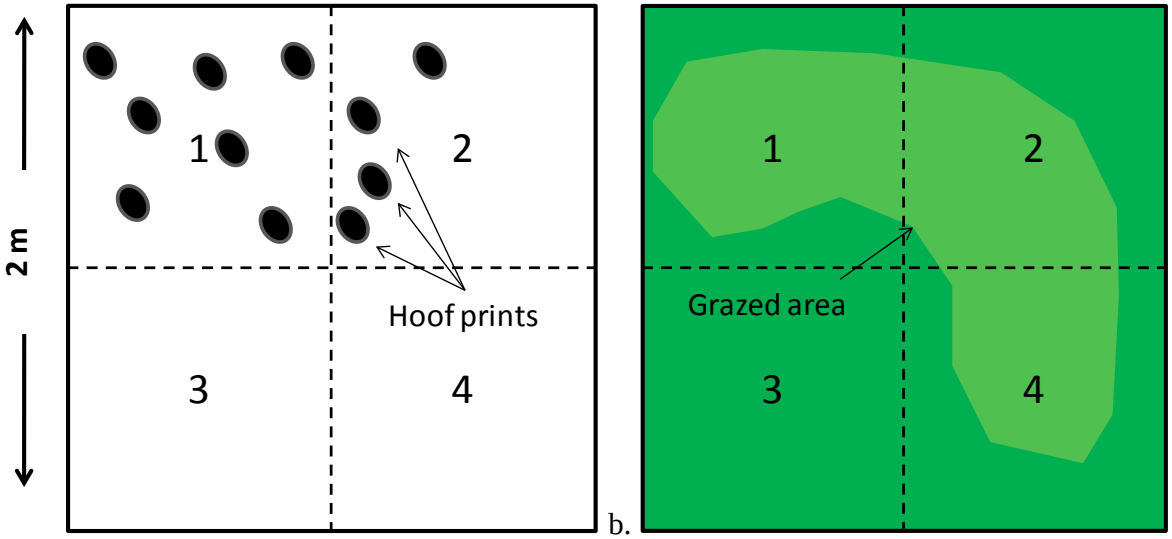
At each relevé, the percentage cover of all vascular plant species, *Sphagnum* (if present), other bryophytes, leaf litter, bare ground, and exposed rock were visually estimated and recorded. All vascular plant species were identified to species, if possible. Voucher specimens were collected for most plots where new or not immediately identifiable species were encountered. A representative sample of bryophytes (mosses) was collected at each relevé. Vascular plant specimens were identified and names assigned according to Webb et al. 1996. Bryophytes were identified using Watson (1981) and Smith (2004).

Environmental Sampling

We recorded standard environmental characteristics of each relevé to determine abiotic conditions, aboveground biomass, and the presence of various disturbances. Water level at the time of sampling was estimated on site as the level of water measured above or below the ground surface in three water depth classes: 1=above ground surface, 2=depth (below ground surface) 0-20 cm, and 3= depth > 20 cm.

A soil sample (0-20 cm depth) was collected in one corner of each relevé with a screw auger. After the top layer (ca. 2 cm) of vegetation was removed, soil texture was evaluated visually and by hand to determine the size of the mineral fraction and the presence of peat or marl. A subsample was collected for subsequent lab analysis. We determined pH within 12 hours using an Omega PHH-65D Field pH Meter. Two replicate samples of approximately 20 ml of soil paste were mixed with 20 ml of distilled water, stirred, and after 20 minutes the pH of the solution was measured. We recorded the average of the two replicates for each relevé sample. We determined organic carbon content through mass loss on ignition for each relevé. We dried each sample overnight at 50°C, then placed 10 g of soil from each into a muffle furnace for one hour at 440°C subtracting final weight from initial dry weight.

We visually estimated both poaching (in Ireland this term is used to refer to post-hole trampling, which we use here, as indicated by hoof prints depressions in the soil surface) and grazing/browsing (evidence of clipped herbaceous plants that were visibly shorter than adjacent ungrazed plants) using an ordinal scale from 0-4 depending upon the number of quadrants in each relevé that were affected (Figure 3). This semi-quantitative approach estimated area grazed, but did not directly measure grazing intensity or document which plant species were preferentially grazed. Most of the evidence of grazing was recorded in herbaceous perennial vegetation, such as in sedge, rush, or forb swards. No attempt was made to discriminate types of grazing animals, although the animals seen included primarily domestic cattle, horses, and sheep. Feral goats were observed nearby on upland ridges, but were not observed in the wetland basins during the time of the study. We believe that most of the current season grazing we observed in the wetlands was by domestic cattle, sheep, and horses.



a. b.

Figure 3. Diagram of livestock disturbance sampling estimate in relevé: a.) The level of poaching was estimated by the presence of hoof prints in each of the four quadrants of the relevé. Here the ordinal estimate would be 2. b.) Grazing/browsing is estimated in a similar way, and here the estimate would be a 3.

Because we expected biomass to have important relationships with the composition and diversity of species present, we collected biomass information in two ways: 1) a direct estimate of dry weight,

and 2) a derived biomass index. To generate true field estimates, above ground biomass samples were collected from the first 48 relevés visited by clipping all live and dead biomass more than 1 cm above the ground surface in two (225 cm^2) samples in opposing corners of the relevé. The samples were dried to a constant weight in the lab and obvious live, dead, and moss proportions recorded. At all relevés, we also estimated biomass with a specially designed meter stick to allow estimation of light penetration through the vegetation horizontally and vertically. The biomass meter had 20 black 2.5 cm diameter dots printed on a ca. 1 m white background and a 15 cm nongraded, pointed tip to penetrate the soil and allow it to stand unassisted for horizontal measurements. For each horizontal estimate (Figure 4a), the number of dots visible were recorded to the half dot when the standing biomass meter was viewed across the relevé from kneeling position (1.2 m above the ground). For the vertical estimate (Figure 4b), the meter stick was placed horizontally on the ground surface and the dots counted from one corner view from the standing position (1.75 m above the ground). Where the vegetation was thick enough to support the biomass meter, it was pushed along the ground surface under the overhanging sward. From the horizontal and vertical dot counts a biomass index was developed by subtracting each from the total possible and averaging the results:

BMI = (20 – horizontal dots counted) + (20 – vertical dots counted) / 2

We later compared dry weight estimates and the biomass index to test the accuracy of the rapid assessment index.

We obtained geographic coordinates of each relevé with a Garmin GPSMAP CSx60 global positioning (GPS) unit. We collected three digital photographs (planview, downtransect, uptransect) with a Nikon Coolpix 5400 (Figure 5a-c). Absolute elevational measurements were attempted with the GPS unit, but it was not sufficiently accurate for the mild relief of the park. Instead, we gave each relevé a relative elevation based on whether it with first, second, or third relevé on the centripetal transect, which were assigned relative elevations of 3 (high), 2 (medium) , and 1 (low), respectively.

a.  b. 

c.  d. 

Figure 4 a-c. a) Biomass meter (calibrated meter stick) viewed a) horizontally, and b) vertically. c) Clipped vegetation biomass sample being dried to a constant weight in the laboratory, d) soil sample collected with screw auger.

a. 

b. 

c. 

Figure 5a-c. Plot vegetation photos: a) Planview of plot, b) downtransect view, c) uptransect view.

Geographic Data Preparation

The National Parks and Wildlife Service provided us with a digital orthophoto (ca. 1 m nominal resolution) for the park and environs. This true color image provided impressive detail of the park landscape and its varied plant communities. This imagery was used as an adjunct to field data collections to infer and correlate field data observations to the larger park landscape.

Floristic Analyses

Curtin (2009) conducted a phytosociological analysis upon the same field data that is on file at National University of Ireland, Galway. The analyses described here illustrate the development and description of mappable wetlands units that should be recognizable to park managers and visitors. The floristic analyses were conducted as a first stage in developing meaningful ecological units, which were then compared with discernable vegetation and geomorphic patterns in a weight of evidence approach to mapping and description.

The vascular plant species frequency and environmental data were analyzed with the multivariate analysis packages PC-Ord and PRIMER to determine floristic groups and the relationship between species distributions and the environmental variables sampled. A hierarchical agglomerative cluster analysis based on Bray-Curtis similarity in floristic composition among relevés was used to identify wetland types. We used the flexible beta linkage mechanism (with beta set at -0.25) to create clusters. McCune and Grace (2002) suggest that the Bray-Curtis (analogous to / flexible beta (-0.25)) approach is space conserving like Ward's methods and provides dendrograms with interpretable groups and minimum chaining. Within PC-Ord, pruning of dendrograms is subjective, based on the level of resolution desired and a visual interpretation of the lengths of individual branches. We corroborated our PC-Ord analyses with cluster analyses in PRIMER-E (2013). The PRIMER-E analyses were similar, except that we used the Group Average linkage mechanism (flexible beta is not an option) and evaluated the significance of clusters with the SIMPROF test. This approach allowed us to compare our subjective pruning decisions with a more formal statistical approach to converge upon a robust classification. We conducted Indicator Species Analysis in PC-Ord as a means of comparing different classification resolutions (McCune and Grace 2002). We tested the final classification with Multiple Response Permutation Procedures (MRPP) in PC-Ord to evaluate the degree strength of the overall classification and to compare average inter sample distances within each group.

We ordinated the floristic data with nonmetric multidimensional scaling (NMDS) in PRIMER-E and plotted species and environmental data jointly to illustrate the relationships between floristic units and the measured environmental variables. We only present environmental variables that had correlation coefficients higher than 0.3 in the final diagram. The environmental variables did not affect the ordination, so our results compose an indirect gradient analysis. We used the BIOENV (Clarke and Ainsworth 1993) procedure in PRIMER to identify the variables most associated with variation in the floristic dataset. BIOENV selects environmental variables, or species "best explaining" community pattern, by maximizing a rank correlation between their respective resemblance matrices.

Identification of Mapping Units

We worked iteratively with the floristic, environmental, and two scales of imagery data (photographs taken at each site and the landscape orthophoto) to identify consistent and interpretable mapping units. Such a-weight-of-evidence approach suggested that some of the floristically distinctive units were not mappable and therefore aggregated and that some of the floristic units were placed in the wrong map class. Nine relevés were moved from the initial floristic classes to such subjectively-created map classes. Five were moved to the turlough floor community, which had been classified as either reedswamp or sedge meadow based on floristic composition. This mapping unit seemed important enough on a parkwide basis, and was a sufficiently discrete and mappable type, to warrant separate description. Environmental data were tabulated and analyzed to generate summary statistics for each wetland mapping unit.

Image Acquisition and Classification

Irish Ordnance Survey orthophotos from 2005 were mosaicked and projected to the TM65_Irish_Grid. GPS data collected at the 96 sample relevé points were used to classify pixels at those locations. The imagery was not taken during the same time period as the field data (some vegetation phenology may be different in field photos taken on the ground in 2008). The GPS has a horizontal accuracy of approximately 10m.

The imagery were subset to the wetlands of interest in the Burren National Park boundary to avoid confusion with agricultural land or large limestone outcrops. A supervised classification was conducted in ERDAS Imagine using training pixels that were selected from GPS data and field photos for each of 10 possible classes (described in subsequent sections) of wetland community types. The classified data were smoothed with the Neighborhood tool in ERDAS's GIS Analysis toolset in order to minimize the speckled ("salt and pepper") appearance of mapped classes. The final, smoothed classification had a minimum mapping unit of approximately 0.01 hectares (10m x 10m).

Analyses of Floristic Diversity

We analyzed species diversity for each wetland type, and the factors best explaining high and low diversity across the wetland dataset as a whole. Relationships between species richness in relevé plots and environmental variables were evaluated by viewing univariate scatterplots, and multivariate regression analyses and tree models. For univariate scatterplots, fitting equations and coefficients of determination were conducted in Excel, which allows rapid exploration of linear and polynomial regression equations. Multivariate analyses were conducted in SYSTAT 12. We checked the dataset for collinearity by viewing Pearson correlation coefficients between all independent variables. Multivariate stepwise linear regression was conducted with the criteria that all new variables had a p-value of <0.15 for entry and < 0.05 for retention with no interaction terms included. The Akaike Information Criterion (AIC) was used to aid comparisons of the strengths of alternate models. To provide an easy visualization of the factors associated with high and low species richness, we prepared regression tree models using the same multivariate dataset. Although less widely used than least-squares regression techniques, regression trees (Breiman et al. 1984) offer several advantages for analyses of field data. They can accommodate heterogeneous datasets that include linear and

categorical variables, often with nonlinear and interacting relationships with the dependent variables in question, and provide descriptions of complex relationships that may be easier to interpret. In this dataset, in which hydrologic, edaphic, vegetation, and livestock use are intercorrelated, it seemed an appropriate adjunct to more traditional regression analyses. Explanatory power of splitting variables is presented as Proportional Reduction in Error (PRE), which is analogous to the coefficient of determination (R^2) in multiple regression models (SYSTAT 2002).

Analyses of Livestock Influences

We used analysis of variance to evaluate the levels of livestock grazing and poaching across the plant communities present, and across each of the three relative elevation classes. Data were also graphed to illustrate the variation in livestock grazing and poaching within and across types.

Results

Biomass Estimation

The dry weight of above ground biomass in 48 clipped samples ranged from 37.5 to 6450 grams/m^2. An exponential regression of the measured dry weight upon the visually estimated Biomass Index explained 71% of the variance across the co-sampled sites (Figure 6). Given the strength of this correlation, we used the regression equation to develop dry weight estimates for the remaining 48 samples based on the biomass index.

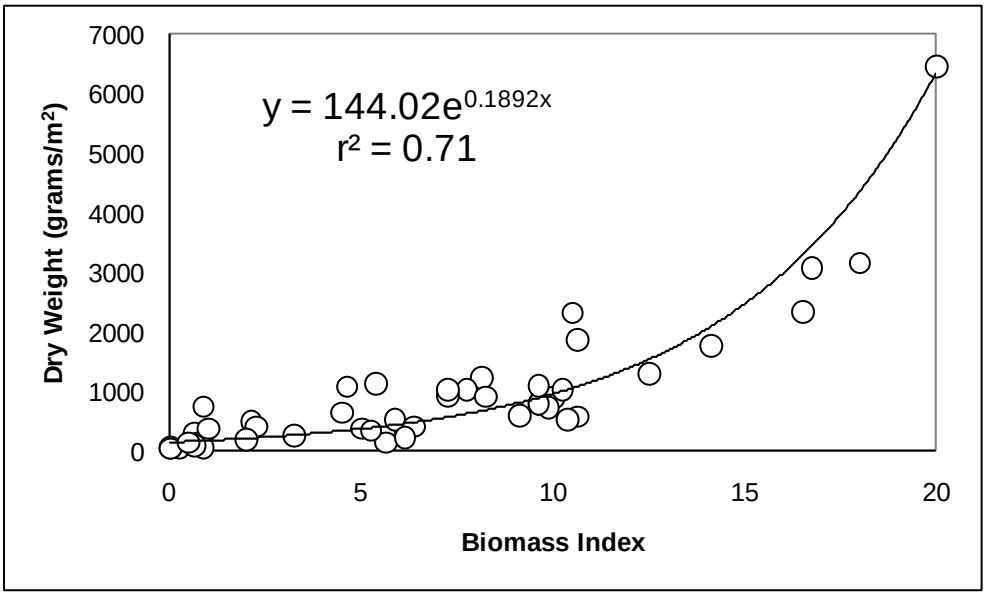


Figure 6. Measured above ground dry weight (g/m^2) of plant material as a function of Biomass Index.

Classification of Wetland Vegetation Communities

A total of 122 vascular plants and 35 bryophyte species were recorded in the field inventory (Curtin 2009). Specimens were identified to species or subspecies by John Curtin and Dr. Micheline Sheehy Skeffington at National University of Ireland, Galway. For the analyses in this report, we used only vascular plant species, and pooled all subspecies of *Carex viridula* (these included *C. viridula* ssp. *viridula*, *C. viridula, spp. flava, C. viridula* ssp. *oedocarpa*, and *C. viridula* ssp. *brachyrhyncha*). The apparent subspecies of *C. viridula* appeared to intergrade in morphology and did not show strong or reliable habitat differences in the field, but the species complex as a whole was associated with flooded turlough floors, and we felt the overall classification would be improved with this refinement. This simplification yielded an analysis dataset of 119 vascular plant species.

The cluster analysis of species abundance data recognized between 10 and 14 plant communities as being optimal for our dataset based on species presence and cover. The SIMPROF function in PRIMER recognized up to 14 significant clusters within the dataset, and subsequent evaluation with Indicator Species Analysis suggested that the optimal numbers of significant indicator species (53 of 119 potential indicator species significant at $p < 0.05$, and average p-value of 0.252 for all species) occurred with 10 groups (Figure 7). These groups generally formed a gradient from temporally

flooded fen and shrubland community types at the upper edges of the wetlands to seasonally and semipermanently flooded types deeper in the wetland basins. They were placed into aggregate classes based on hydrologic and nutrient status (Table 1).

Results from MRPP suggested that the classification was strong overall, with a chance-corrected within-group agreement far higher than expected by chance ($A = 0.34$, $p < 0.001$). Across all ten groups, the average within-group Bray-Curtis distance was 0.57 against an expected random distance of 0.87. However, the Bray-Curtis distances within individual groups ranged from a low of 0.29 for Sawsedge Reedswamp, which was highly uniform, to a high of 0.86 for the Marl Flat community type, which was relatively species-poor and variable in composition.

Burren Wetlands Classification

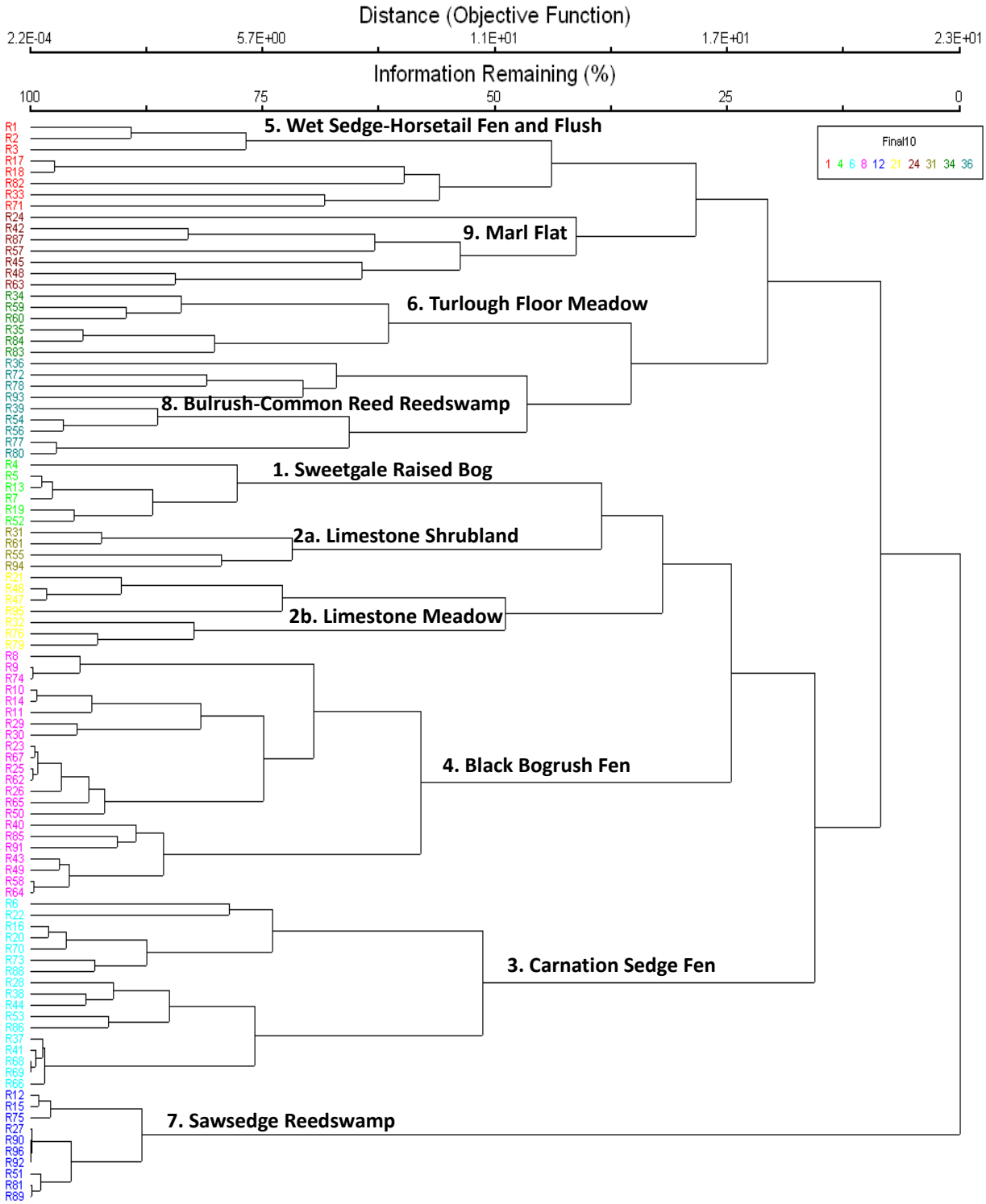


Figure 7. Dendrogram from hierarchical cluster analysis with community types/mapping units overlaid.

Table 1. Comparison of mapping units and vegetation types with Curtin (2009) groups and recognized phytosociological and habitat classes.

Map Unit Number	Hydrologic Class	Nutrient Status	Community Type	Curtin (2009)[1] Group	Phytosociological Class(es)	Phytosociological Authorities	Fossitt (2000)[6] Code	Characteristic Species
1	Temporarily Flooded	Ombrotrophic	***Raised Bog***	Group 3	*Myricetum gale* association	Ivimey-Cook and Proctor 1966[2]	*PB1*	*Molinia cearulea, Myrica gale, Erica tetralix, Calluna vulgaris, Sphagnum* sp.
2a	Temporarily Flooded	Minerotrophic	***Limestone Shrubland***	Group 1	*Potentilla fruticosa* stand	Ivimey-Cook and Proctor 1966[2]	*(ER2)*	*Potentilla fruticosa, Rhamnus cathartica, Thymus polytrichus*
2b	Temporarily Flooded	Minerotrophic	***Limestone Meadow***	Group 1	Potentilla fruticosa stand	Ivimey-Cook and Proctor 1966[2]	*(ER2)*	*Carex flacca, Agrostis* sp.
3	Seasonally Flooded	Minerotrophic	***Carnation Sedge Fen***	Group 2	*Carex panicea-C. flava* agg. Community	O'Connell et al. 1984[3]	*PF1*	*Carex panicea, Cirsium dissectum, Carex hostiana*
4	Seasonally Flooded	Minerotrophic	***Black Bogrush Fen***	Group 1	*Schoenus nigricans-Cirsium dissectum* association	Ivimey-Cook and Proctor 1966[2], O'Connell et al. 1984[3], O'Croidain and Doyle 1997[4]	*PF1*	*Schoenus nigricans*
5	Seasonally Flooded	Minerotrophic	***Wet Sedge-Horsetail Fen and Flush***	Group 9	*Equisetum fluviatile-Caltha palustris* group	Rodwell 1998[5]	*PF1*	*Carex vesicaria, Equisetum arvense, Caltha palustris, Eleocharis palustris*
6	Seasonally Flooded	Minerotrophic	***Turlough Floor Meadow***	Group 6	*Carex panicea-C. flava* agg. Community, *Carex elata* community, *Litorella uniflora-Baldellia ranunculoides* association	Ivimey-Cook and Proctor 1966[2], O'Connell et al. 1984[3]	*FL6*	*Carex viridula, Carex elata, Baldellia ranunculoides, Ranunculus flammula*
7	Semi-permanently Flooded	Minerotrophic	***Sawsedge Fen***	Group 11	Cladium mariscus-*Utricularia* intermedia sub-nodum, *Cladium marisci* community	Ivimey-Cook and Proctor 1966[2], O'Connell et al. 1984[3]	*FS1*	*Cladium mariscus*
8	Semi-permanently Flooded	Minerotrophic	***Bulrush-Common Reed***	Group 10	*Scirpus lacustris-Phragmites communis* nodum	Ivimey-Cook and Proctor 1966[2]	*FS1*	*Schoenoplectus lacustris, Phragmites australis*

Map Unit Number	Hydrologic Class	Nutrient Status	Community Type	Curtin (2009)[1] Group	Phytosociological Class(es)	Phytosociological Authorities	Fossitt (2000)[6] Code	Characteristic Species
			Reedswamp					
9	Semi-permanently Flooded	Minerotrophic	***Sparsely Vegetated Marl Flat***	Group5, Group 6, Group 7	*Litorella uniflora-Baldellia ranunculoides* association, *Eleocharis multicaulis-Scorpidium scorpioides* sub-assocation	Ivimey-Cook and Proctor 1966[2]	*(FL3)*	*Litorella uniflora, Eleocharis multicaulis*
10	Permanently Flooded	Oligotrophic	**Open Water (Aquatic)**	NA	NA	NA	*FL3/FL4*	*Nymphaea alba*

1. Curtin, J. 2009. *An Investigation into the Wetland Vegetation of the Burren National Park*. B.Sc.(Hons) Thesis. National University of Ireland, Galway.

2. Ivimey-Cook, R.B. and Proctor, M.C.F. 1966 The plant communities of the Burren, Co. Clare. *Proceedings of the Royal Irish Academy* 64B, 211–301.

3. O'Connell, M. O. J.B. Ryan, and B. A. MacGowran. 1984. Wetland communities in Ireland: a phytosociological review. pp 303-364 In P.D. Moore (ed) *European Mires*. Academic Press, London, UK.

4. Ó Críodáin C., and G. J. Doyle. 1997. *Schoenetum nigricans,* the *Schoenus* fen and flush vegetation of Ireland. *Biology and Environment. 94B(2): 127-144.*

5. Rodwell, J.S. 1998. *British Plant Communities: Aquatic communities, Swamps, and Tall Herb Fens*. Cambridge University Press.

6. Fossitt, J. 2000. *A Guide to the Habitats of Ireland*. The Heritage Council, Kilkenny.

Relationships between Vegetation and Environment

The BIOENV procedure in PRIMER-E created 20 models to explain the variation in the species data; the most powerful model explained up to 46% of the variance in the species data, but all explained over 40%. Rather than present a single model, we tallied the number of times each of 13 explanatory variables was selected in the top 20 models to quantitatively portray how often each variable was selected (Figure 8). Water depth class (WTDPCLS) and percentage bare ground (BARE) were selected in all 20 models, followed by biomass index (BIOMASS) which was selected 19 times. Poaching (POACH), litter depth (LDEPTH), and marl (MARL) were all selected in at least 12 models. We concluded that these variables were the most associated with the variation in the vegetation data.

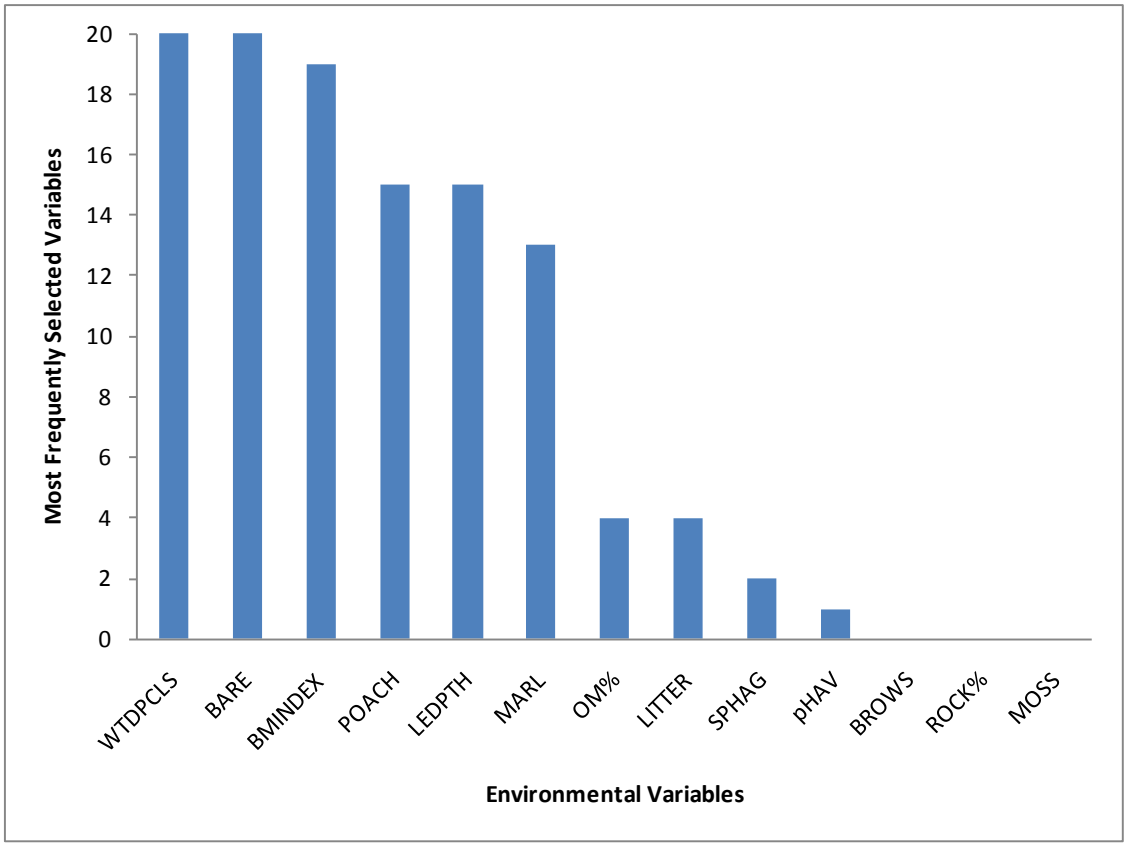


Figure 8. Histogram of most frequently chosen environmental variables out of 20 possible models selected by the BIOENV procedure in PRIMER. Variable Definitions on X Axis: WTDPCLS= Water depth class, BARE= percentage bare ground in relevé, BMINDEX = biomass index, POACH= poaching in relevé, LDEPTH= litter depth in relevé, MARL= marl presence in soil, OM%=percent organic matter in soil, LITTER=litter cover in relevé, SPHAG=sphagnum present in relevé, pHAV=average soil pH, BROWS=browsing in relevé, ROCK%=percent exposed rock cover in relevé, MOSS=moss cover (all species) in relevé.

PRIMER-E yielded a two dimensional NMDS ordination for the dataset that was quite clear and of adequately low stress (0.17) to provide a quick overview of the interrelationships between the community types and environmental variables. Axis 1, negatively associated with WTDPCL, and which appeared to describe a hydrological gradient from the driest sites at left to the wettest sites at

right, explained 22.9% of the variance in the Bray-Curtis distance matrix. Axis 2, positively associated with BIOMASS and negatively associated with MARL explained 23.4 % of the variance in the Bray-Curtis distance matrix, for a cumulative total of 46.3% variance explained. Generally, the wetland community types of the park grade into one another (Figure 9), but the vegetation communities selected in cluster analysis also appeared to show recognizable grouping in the ordination. The variability across the different relevés in each community appeared to depend upon the number of species typically occurring in each community. Species rich Carnation Sedge and Black Bogrush communities showed relatively compact groupings in the ordination diagram whereas the more variable and species-poor reedswamp communities showed more scatter in the diagrams. In contrast, Sawsedge Fen, although species poor, had a largely predictable composition and tight grouping in the ordination space (Figure 9).

The ordination diagram illustrates the general arrangements of the community types in relationship to the environmental variables measured. Water depth class was most negatively correlated with the wettest vegetation communities, including the Bulrush-Common Reed Reedswamp and Sawsedge Fen communities and Wet Sedge Fen and Flush communities. The marl flat communities were most correlated with bare soil, high pH, and the presence of marl. Limestone shrubland and meadow communities were associated with exposed rock and the higher water depth classes. Raised Bog, and Black Bogrush Fen, and especially Sawsedge Fen communities were associated with the highest biomass index.

The findings from the BIOENV and ordination match well with field observations, suggesting that the wetland gradients of most importance in park wetlands are the hydrologic gradient from wetland edge to center, the cover and pH gradient from bog or poor fen to rich fen and bare marl flat, and the biomass gradient from very low biomass communities on turlough floors or grazed sedge meadows to sawsedge fens. These gradients are not completely independent. Low biomass communities, for instance, were typically in barren high pH marl habitats, which are flooded for much of the year.

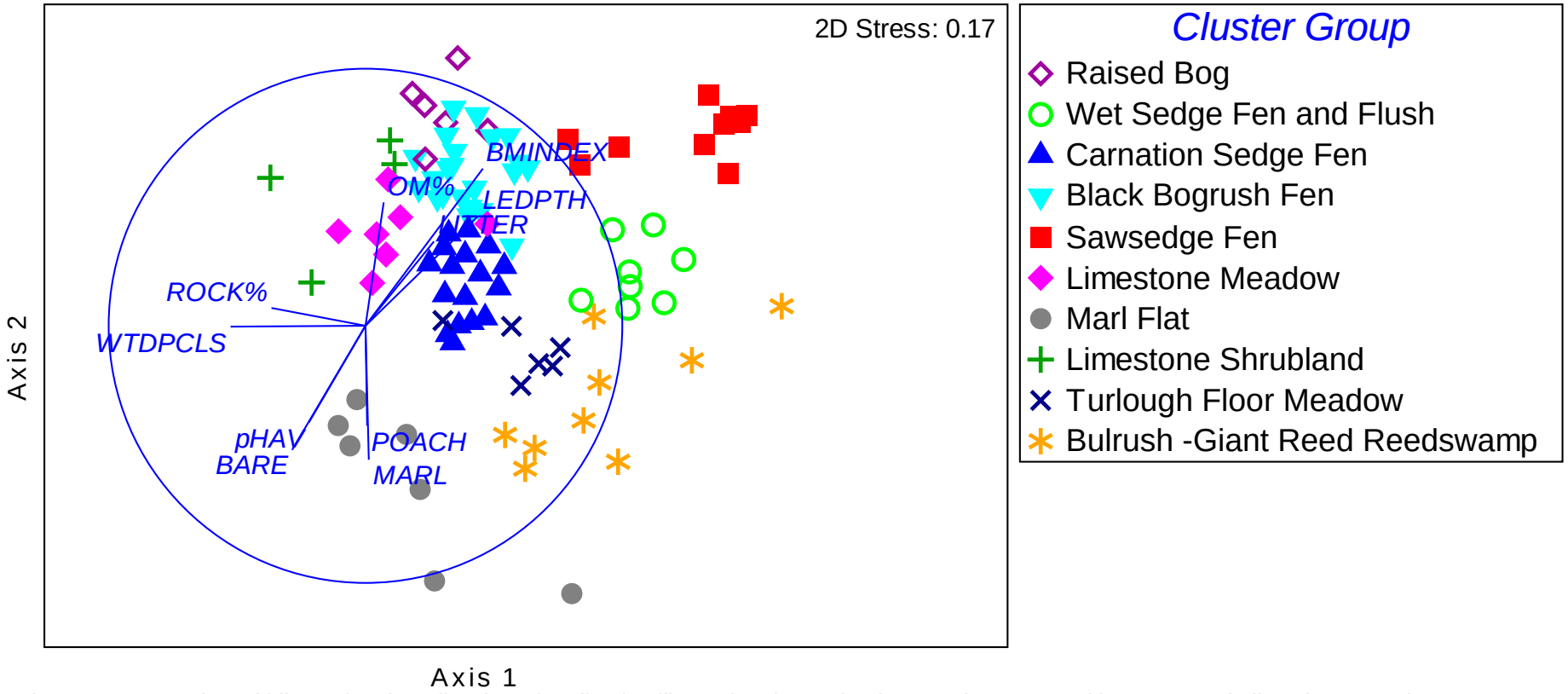
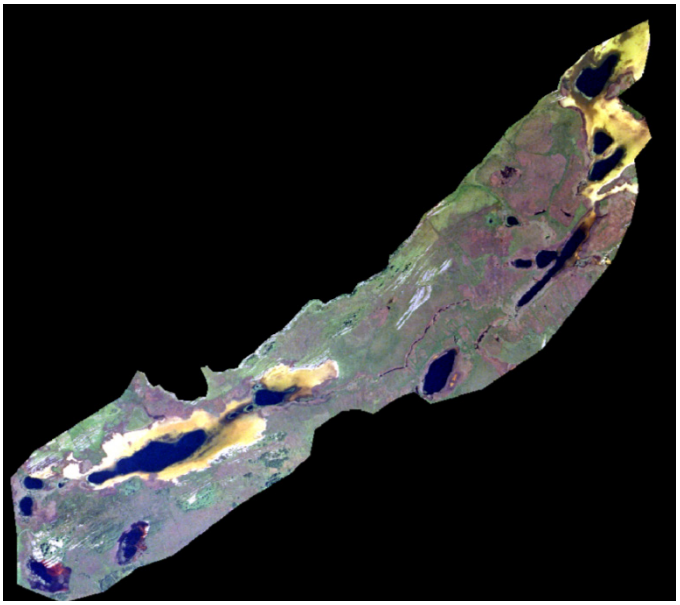


Figure 9. Nonmetric Multidimensional Scaling (NMS) ordination illustrating the wetland vegetation communities types and all environmental variables with a Pearsons correlation coefficient greater than 0.3 with ordination axes. Axis 1 and 2 explain 22.9% and 23.4 % of the variance in the Bray-Curtis distance matrix ,respectively. Stress for the ordination is 0.17. Variable Definitions: WTDPCLS= Water depth class, BARE= percentage bare ground in relevé, BMINDEX = biomass index, POACH= poaching in relevé, LEDPTH= litter depth in relevé, MARL= marl presence in soil, OM%=percent organic matter in soil, LITTER=litter cover in relevé, SPHAG=sphagnum present in relevé, pHAV=average soil pH, BROWS=browsing in relevé, ROCK%=percent exposed rock cover in relevé, MOSS=moss cover (all species) in relevé.

Image Classification

Because the major mapping units in the park are clearly differentiated by color and texture in the original orthophoto (Figure 10a), the supervised classification provided fairly clear mapping units in the park that were easily interpretable from field photos (Figure 10b; embedded images in Figure 11). The 7x7 pixel filter created more continuous and easily distinguished mapping units that provide an interpretable description of the major wetland plant community types in the park.

a.



b.

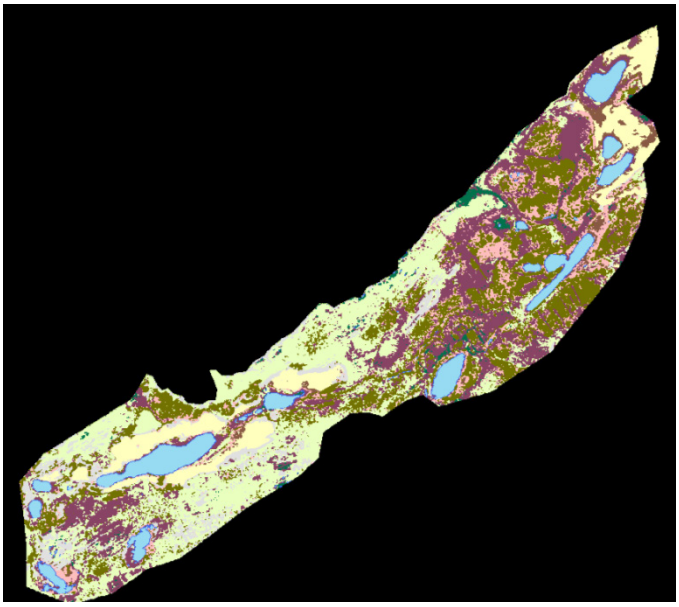


Figure 10. Image classification: a) original orthophoto and b) ERDAS Imagine image classification for Ballyeighter Peatland Complex.

Wetland Community Types of the Burren National Park

In this section, we provide brief tabular summaries (mean ± standard deviation) of biological and environmental variables and narrative descriptions of each of the wetland plant community types identified in the Burren National Park, followed by images of the type and of characteristic vascular plants. The community types are presented by hydrological class from the temporarily flooded upper wetland communities through the seasonally flooded fen and turlough floor communities to the permanently and semipermanently flooded community types at the lowest points in the wetland basins. Each wetland basin shows a characteristic mosaic of the types in a unique pattern reflecting its hydrology and topography, and soil pH. Figure 11 provides an example of how a number of the common community types fit together in a wetland complex.

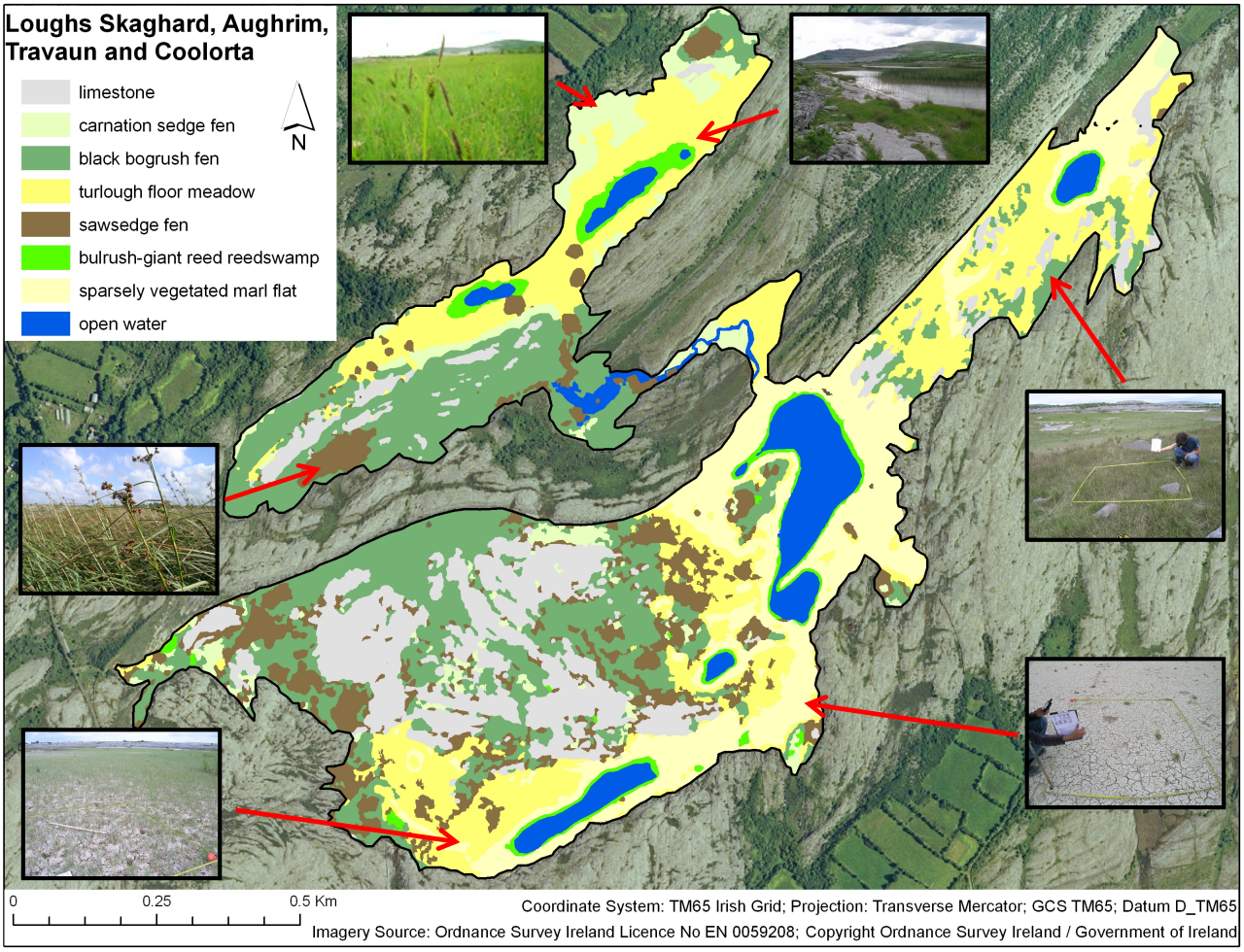


Figure 11. Overview of major wetland community types of the Skaghard-Travaun-Coolorta-AughrimTurlough Complex.

Wetland Community Type 1. Raised Bog.

Number of Relevés (n): 5

Dominant Plant Species: *Myrica gale, Erica tetralix, Molinea cerulea*

Indicator Species: Any of the above and *Narthecium ossifragum*

Species Richness: 13.2 ± 4.1 species/4 m^2, Range: 8-18 species.

Physiognomy: Low mixed shrubland in dense sward of herbaceous graminoids.

Relative Elevation and Hydrology: Occurs at high relative elevations (2.8±0.5), but with intermediate Water Depth Class (2.0±0.7)

Soil: Peat, moderately acid (Organic matter = 70.7% ± 8.8%; pH= 5.9 ± 0.6; no marl present)

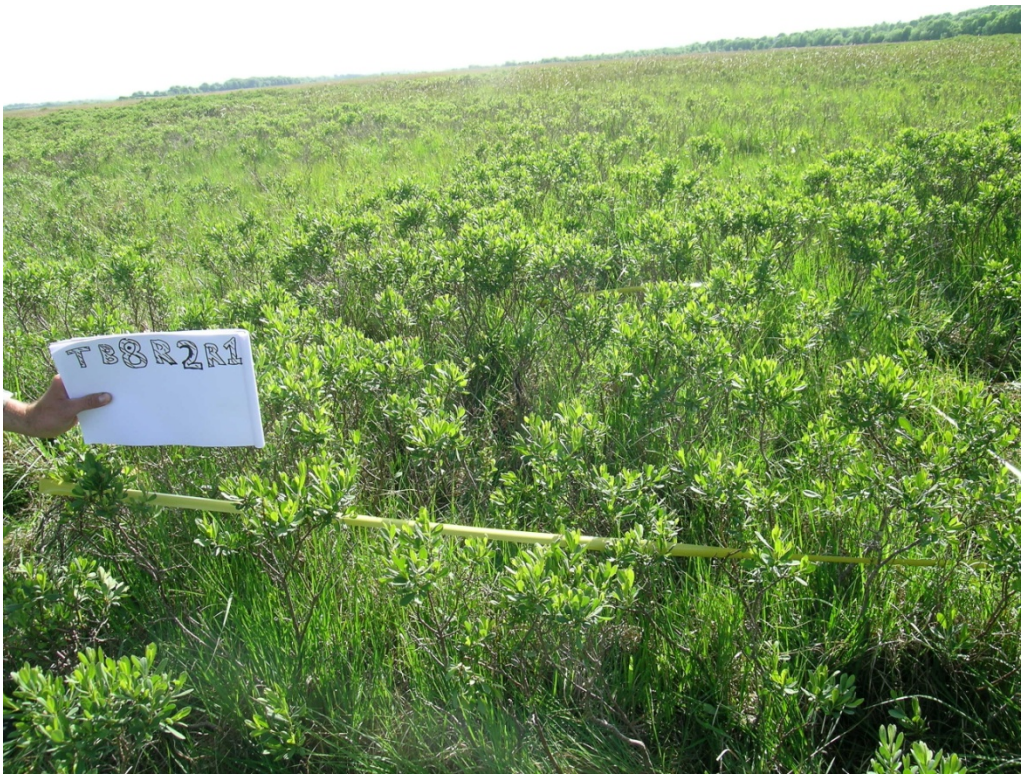
Biomass: Biomass Index =10.8±3.0; Biomass (Dry Weight) Estimate= 1302.3±944.4 gm/m^2

Ground Cover: Total Vegetation Cover= 119.1%± 23.8%; Bare Ground= 0.0%± 0.0%; Exposed Rock=0.0% ± 0.0%; Litter= 21.0% ± 8.9%; Moss= 4.6% ± 5.0%;

Livestock Disturbance Indices: Browsing= 0.0; Poaching= 0.6 ± 0.9.

General Description: The Raised Bog community type is limited to the higher peat surfaces in the Ballyeighter Peatland complex of BNP, although several other poor fens in the park, such as Lough Gealáin Fen, have environmental and floristic similarities. The extent of intact peat surface is quite limited in the wetland and primarily occurs to the eastern edge of the complex. This is a distinctive wetland type in the park, characterized by a low shrub matrix of the acid-loving peatland species including bog myrtle (*Myrica gale*), cross-leaved heath (*Erica tetralix*), ling heather (*Calluna vulgaris*), within a dense sward of purple moor grass (*Molinia caerulea*), star sedge (*Carex echinata*), flea sedge (*C. pulicaris*), and the normally alkaline-associated species black bogrush (*Schoenus nigricans*). The importance of *Molinia*, and especially *Schoenus*, in the blanket bog environments of far western Ireland have been linked to effects of oceanic electrolyte deposition, and high pH values of the bog soil solution (Gorham 1953, Sparling 1967). These characteristics occur at Ballyeighter, where *Schoenus* is co-dominant in the graminoid layer, and pH is at the upper range for ombrotrophic bogs in Ireland, but the proximity of calcareous rock and water may more likely be responsible for this than oceanic influence. Topographically, the bog is confined to a basin and more closely resembles a raised bog (Proctor 2010), despite the frequent presence of blanket bog species. Forbs are scattered and of low abundance, including bog asphodel (*Narthecium ossifragum*), tormentil (*Potentilla erecta*), and sundew (*Drosera rotundifolia*). *Sphagnum* moss species form a dense layer along the ground surface, but are typically under the dense vascular graminoid layer. Where peat cutting has lowered the ground surface approximately 30 cm, this community type grades into the Black Bogrush Fen community type, which has higher pH, fewer calcifuge and more widespread calcium-loving species.

a.



b.

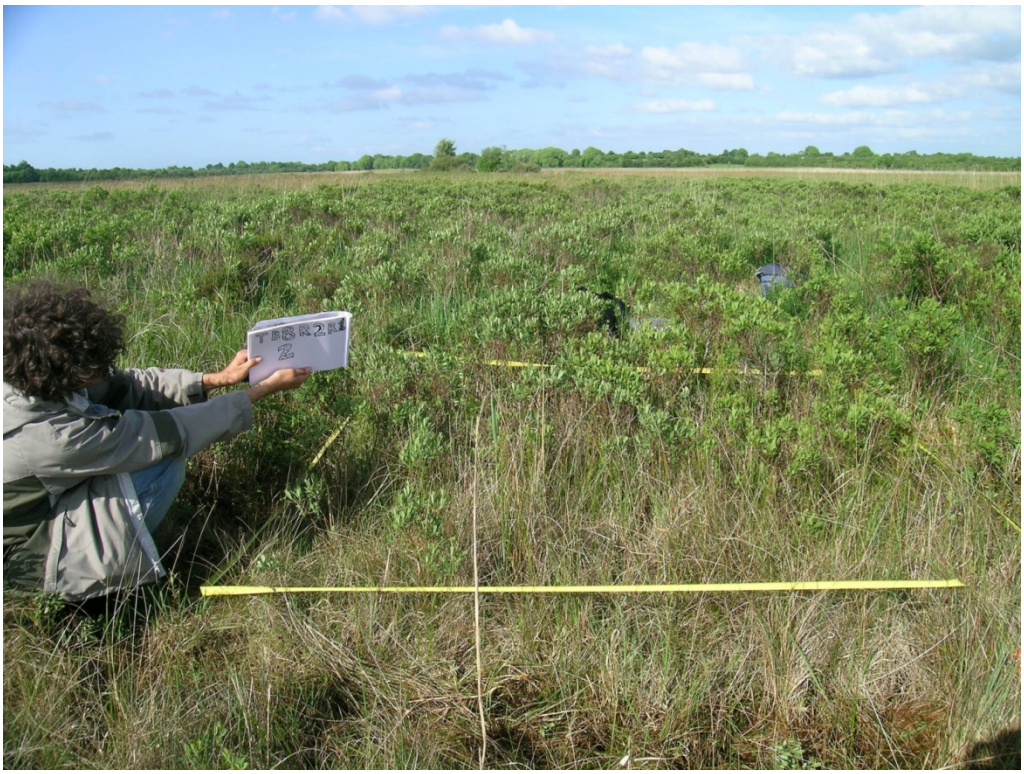


Figure 12. Raised Bog community type in Burren National Park: a) oblique view of sampling relevé on remnant peat surface, b) view of sampling relevé at edge of peat surface, showing transition to Black Bogrush Community Type on cutover peat (foreground).

a.  b. 

c.  d. 

e. 

f. 

g. 

Figure 13. Common vascular plant species of the Raised Bog community type in Burren National Park: a) close up of bog myrtle (*Myrica gale*), b) cross-leaved heath (*Erica tetralix*). c) tormentil (*Potentilla erecta*), d) round-leaved sundew (*Drosera rotundifolia*), e) bog asphodel (*Narthecium ossifragum*), f) flea sedge (*Carex pulicaris*), and g) star sedge (*Carex echinata*).

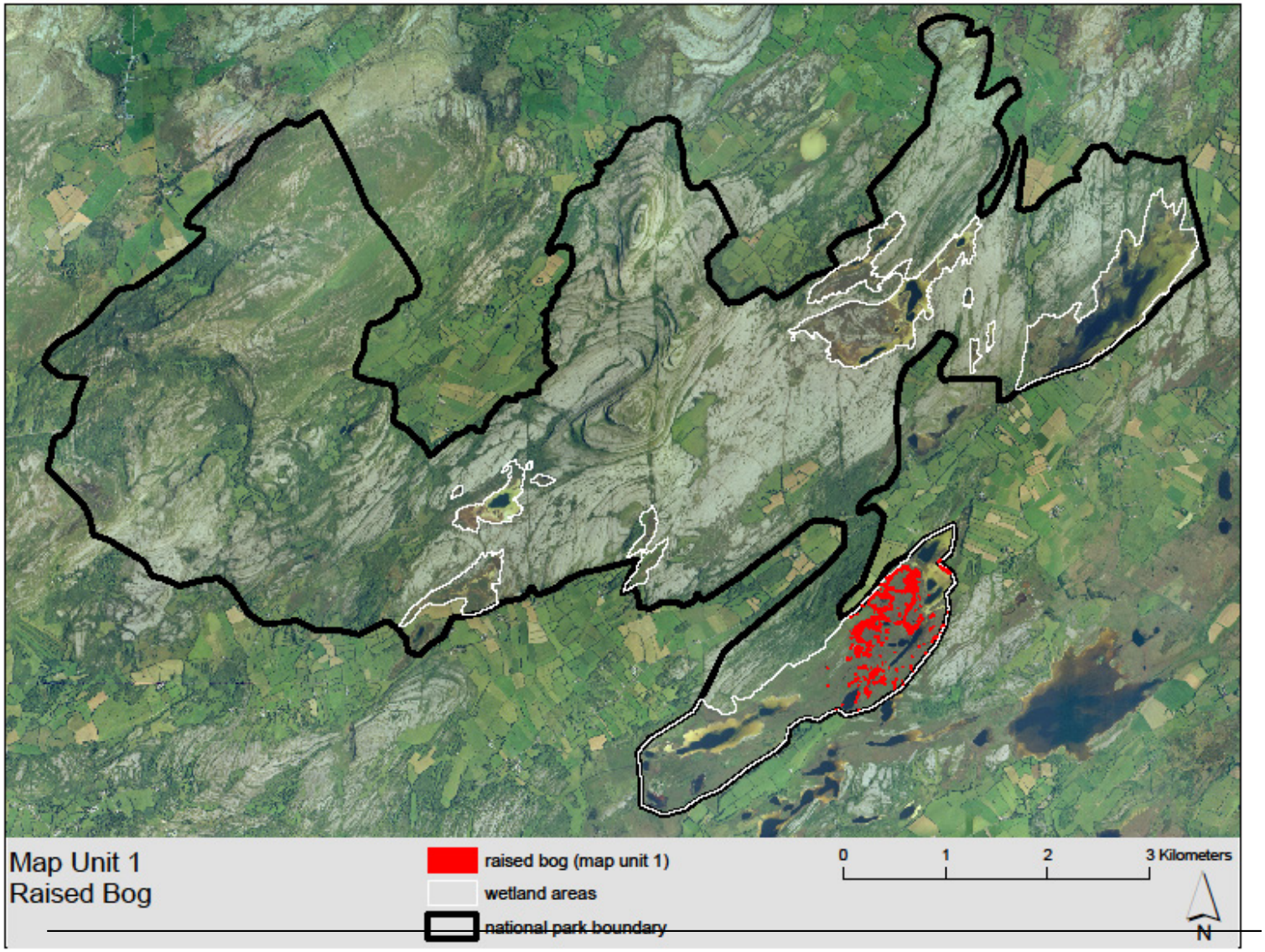


Figure 14. Distribution of the Raised Bog Community Type (Map Unit 1) in sampled wetlands of Burren National Park.

Wetland Community Type 2. Flooded Limestone Pavement

Subtype A-Limestone Shrubland

Number of Relevés (n): 4

Dominant Plant Species: *Rhamnus cathartica, Potentilla fruticosa, Prunus spinosa*

Indicator Species: All the above plus *Thymus praecox, Lotus corniculatus, Sesleria caerulea*

Species Richness: 17.5 ± 5.3 species/4 m^2, Range: 13-25 species.

Physiognomy: Low mixed sparse shrubland with scattered herbs.

Relative Elevation and Hydrology: Occurs at highest relative elevations (3.0±0.0), and depth to water class (3.0±0.0)

Soil: Discontinuous, but with moderate organic content, alkaline (Organic matter = 35.7 ± 10.1%; pH= 7.8 ± 0.7; marl present in 25% of samples, Litter Depth= 1.8 ± 1.7 cm)

Biomass: Biomass Index = 2.9±1.5; Biomass (Dry Weight) Estimate= 256.1±76.6 gm/m^2

Ground Cover: Total Vegetation Cover= 83.4%± 36.4%; Bare Ground= 37.5%± 24.7%; Exposed Rock=37.5% ± 24.7%; Litter= 4.0% ± 4.5%; Moss= 3.4% ± 4.5%;

Livestock Disturbance: Browsing= 0.0; Poaching= 0.0.

General Description: The Limestone Shrubland community type occurs around the margins of the turloughs, in areas that are shallowly flooded in the wet season. Rafted debris and the moss *Cinclodotus fontinaloides* suggest some sites can be up to 2 m underwater during the winter season, but most were completely dry at the time of sampling. This is the most species-rich of the wetland plant communities in the park, with many non-wetland species present, especially woody species, grasses, and forbs. Woody species such as shrubby cinquefoil (*Potentilla fruticosa),* alder buckthorne *(Frangula alnus),* purging buckthorne (*Rhamnus cathartica*), and Burnet rose (*Rosa pimpinellifolia*) dominate in biomass, and in sharp contrast to the Raised Bog Type, Ericaceous shrubs are absent. Subshrubs are also common but form a discontinuous layer, including birds-foot trefoil (*Lotus corniculatus*) and thyme (*Thymus praecox*). Herbs form a patchy, rich groundlayer with many species of low constancy. The most common graminoids include the flaccid sedge (*Carex flacca*), Fiorin grass (*Agrostis stolonifera*), and red fescue (*Festuca rubra*). Forbs include Devil's bit scabious (*Succissa pratensis*), dog violet (*Viola* cf. *reginiana*), turlough or fen violet (*Viola persicifolia*), northern bedstraw (*Galium boreale*), common cinquefoil (*Potentilla palustris*), and the strikingly beautiful bloody crane's bill (*Geranium sanguineum*). Many of the species are of dwarfed stature due to the shallow soil horizon. Clints, grykes, and thin soil lenses create a diversity of microhabitats. Because the Limestone Shrubland grades into the Limestone Meadow subtype and the upland limestone pavement, it is not clearly delineated as a mapping unit in this report. Rather it is considered a likely type in peripheral areas of all the turlough basins of the park.



Figure 15. Overview and common vascular plant species of the Limestone Shrubland community type in Burren National Park: a) Plot overview. b) shrubby cinquefoil (*Potentilla fruticosa*), c) alder buckthorne (*Frangula alnus*), d) burnet rose (*Rosa pimpinellifolia*), e) wild thyme (*Thymus praecox*), and f) bloody crane's bill (*Geranium sanguineum*).

Subtype B-Limestone Meadow

Number of Relevés (n): 6

Dominant Plant Species: *Carex flacca, Agrostis* spp., *Carex panicea*

Indicator Species: *Carex flacca*

Species Richness: 13.2 ± 3.7 species/4 m^2, Range: 7-17 species.

Physiognomy: Discontinuous herbaceous meadow.

Relative Elevation and Hydrology: Occurs at somewhat high relative elevations (2.5±0.6), and high Water Depth Class (3.0±0.0)

Soil: Discontinuous, with relatively low organic content, alkaline (Organic matter = 17.5 ± 7.7%; pH= 7.8 ± 0.4; marl present in 50% of samples, Litter Depth= 0.8 ± 1.0 cm)

Biomass: Biomass Index = 4.4±4.3; Biomass (Dry Weight) Estimate= 436.6±375.3 gm/m^2

Ground Cover: Total Vegetation Cover= 51.1%± 30.8%; Bare Ground= 43.3%± 37.9%; Exposed Rock=43.3% ± 37.9%; Litter= 2.8% ± 2.5%; Moss= 0.8% ± 0.8%;

Livestock Disturbance: Browsing= 0.2± 0.4; Poaching= 0.2± 0.4.

General Description: The Limestone Meadow community type occurs around the margins of the turloughs, in areas that are shallowly flooded in the wet season. Rafted debris and the moss *Cinclodotis fontinalis* suggest some sites can be up to 2 m underwater during the winter season, but most were completely dry at the time of sampling. They are among the more species-rich of the wetland plant communities in the park, but with fewer upland forbs and woody plants than the Limestone Shrubland. The herb layer is dominated by graminoids, with higher herbaceous biomass and more continuous cover than the Limestone Shrubland type. Flaccid sedge (*Carex flacca*) is the most characteristic species of this type, but widespread graminoids such as purple moor grass (*Molinia caerulea*), carnation sedge (*Carex panicea*), and tawny sedge (*Carex hostiana*) are equally common. Because it occurs at slightly lower relative elevations, the Limestone Meadow community type appears to be an intermediate type between the Limestone Shrubland type and the fen types which occur at intermediate elevations. Clints, grykes, and thin soil lenses create a diversity of microhabitats. Because the Limestone Meadow grades into the Limestone Shrubland Subtype and the upland limestone pavement, it is not clearly delineated as a mapping unit in this report. Rather it is considered a likely type in peripheral areas of all the turlough basins of the park.

a. 

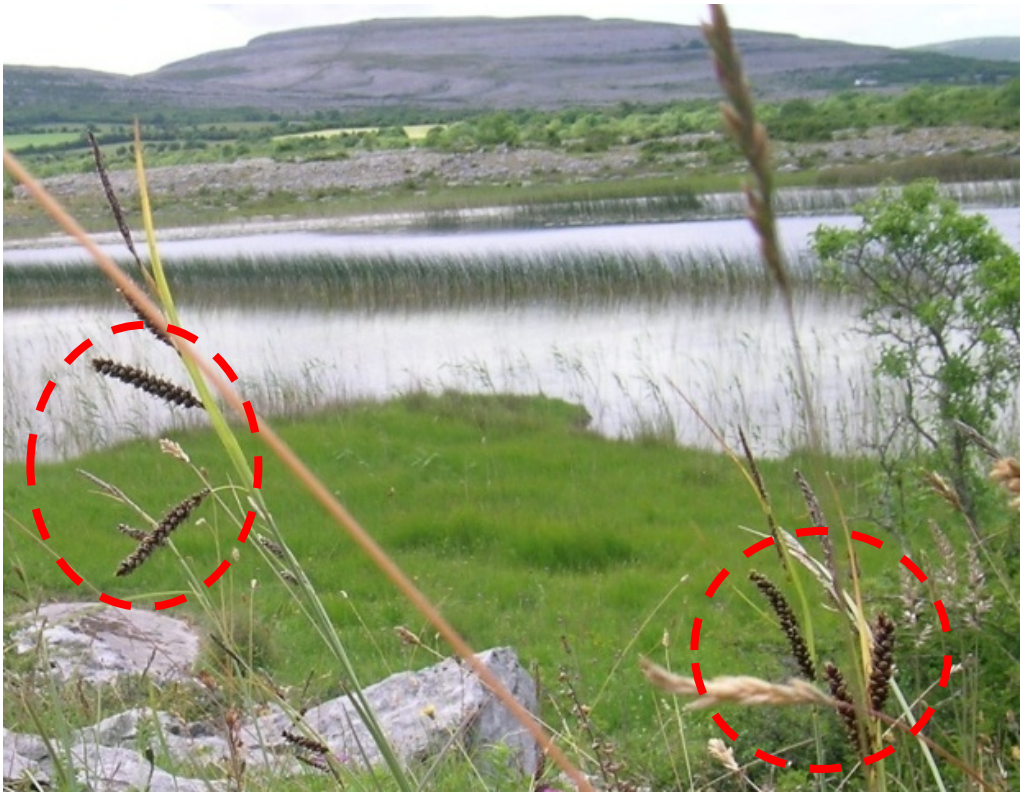
b. 

Figure 16. Overview and common vascular plants of the Limestone Meadow community type: a) overview of sampling relevé, b) flaccid sedge (*Carex flacca*).

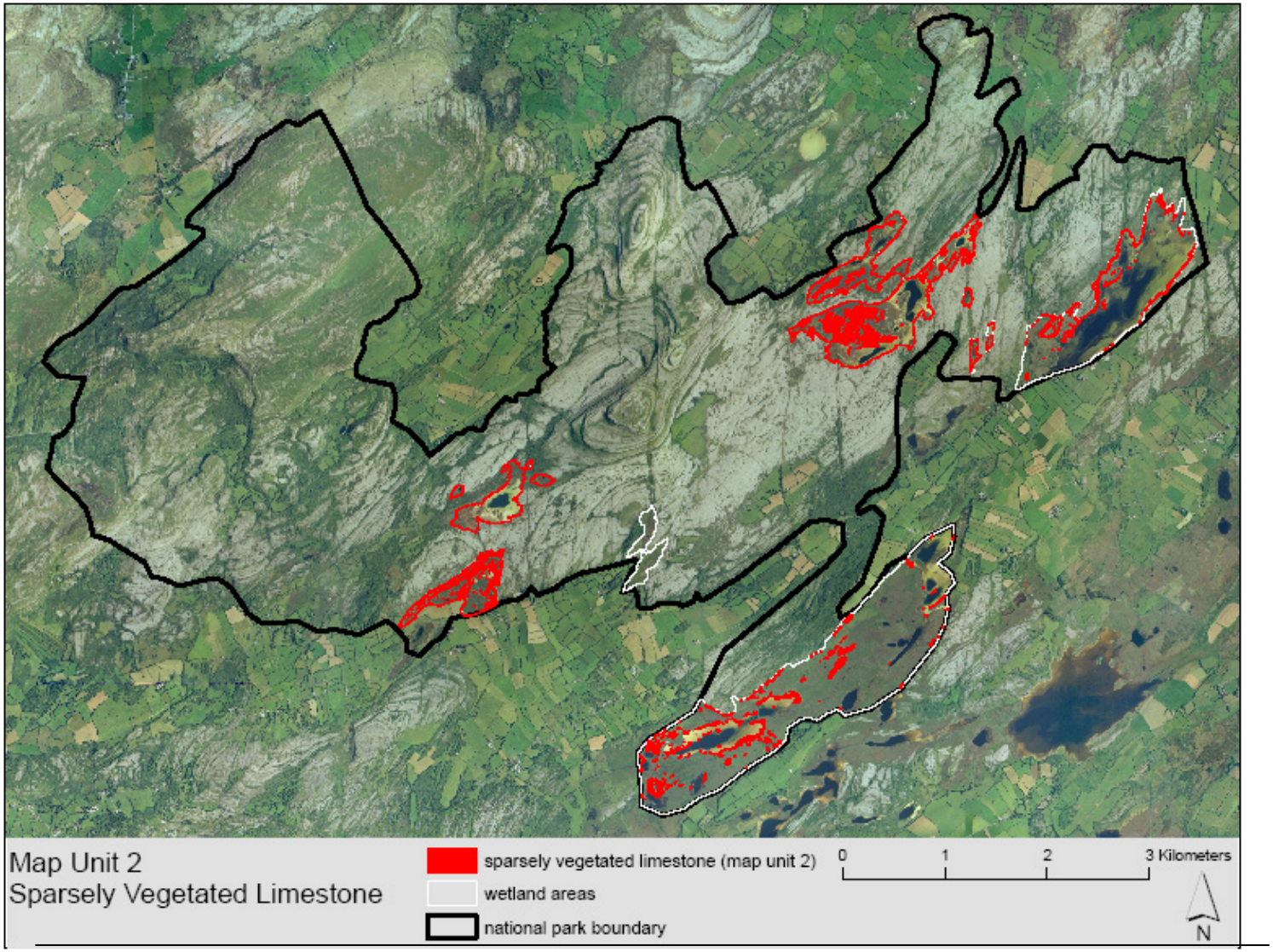


Figure 17. Distribution of the sparsely vegetated Limestone community types (Map Unit 2) in sampled wetlands of Burren National Park.

A. Seasonally-Flooded, Middle Wetland Communities

Wetland Community Type 3. Carnation Sedge Fen

Number of Relevés (n): 16

Dominant Plant Species: *Carex panicea, C. hostiana*

Indicator Species: *Carex panicea*

Species Richness: 13.6 ± 6.7 species/4 m^2, Range: 8-31 species.

Physiognomy: Herbaceous meadow.

Relative Elevation and Hydrology: Occurs at intermediate relative elevations (2.3±0.8), and high Water Depth Class (2.8±0.4)

Soil: Peaty, with moderately high organic content, alkaline (Organic matter = 45.7 ± 22.0%; pH= 7.3 ± 0.6; marl present in 44% of samples, Litter Depth= 1.3 ± 1.0 cm)

Biomass: Biomass Index = 3.7±3.5; Biomass (Dry Weight) Estimate= 365.4±318.6 gm/m^2

Ground Cover: Total Vegetation Cover= 79.8%± 25.5%; Bare Ground= 8.6%± 16.0%; Exposed Rock=5.4% ± 13.0%; Litter= 8.8% ± 9.8%; Moss= 6.8% ± 10.2%;

Livestock Disturbance: Browsing= 1.3± 1.9; Poaching= 0.9± 1.4.

General Description: The Carnation Sedge community type is the second most common fen type in the Park forming extensive lawns around the edges of the wetland basins. It usually occurs at intermediate relative elevations, with similar or slightly lower relative elevation than the Black Bogrush community type, but the two are poorly differentiated hydrologically. The Carnation Sedge type has lower biomass and higher species richness than the Black Bogrush type. Carnation sedge occurs in all stands, usually dominating or co-dominating with tawny sedge (*Carex hostiana*), black bogrush, and with little green sedge (*C. viridula*). Other graminoids include jointed rush (*Juncus articulatus*), common sedge (*C. nigra*), and purple moor grass. The most commonly seen forbs are water mint (*Mentha aquatica*), bog thistle (*Cirsium dissectum*), marsh pennywort (*Hydrocotyle vulgaris*), marsh cinquefoil, (*Potentilla palustris*), and devil's bit (*Succissa pratensis*), with many others occurring less frequently. This type appears to tolerate close grazing, with low cropped swards maintaining a high cover of sedges, but also showing high richness of forbs and subdominant grasses, including brookweed (*Samolus valerandi*), selfheal (*Prunella vulgaris*), fall hawkbit (*Leontodon autumnalis*), bird's-foot trefoil (*Lotus corniculatus*), bent grass (*Agrostis canina*), quaking grass (*Briza media*), and others.

a.



b.



Figure 18. View of sampling relevés in Carnation Sedge Fen community types in a) ungrazed, and b) grazed conditions.



Figure 19. Common plant species of the Carnation Sedge community type in Burren National Park: a) carnation sedge (*Carex panicea*), b) tawny sedge (*Carex hostiana*), c) bog thistle (*Cirsium dissectum*), d) Devil's bit scabious (*Succisa pratensis*), e) marsh pennywort (*Hydrocotyle vulgaris*), f) water mint (*Mentha aquatica*), and g) common cinquefoil (*Potentilla palustris*).

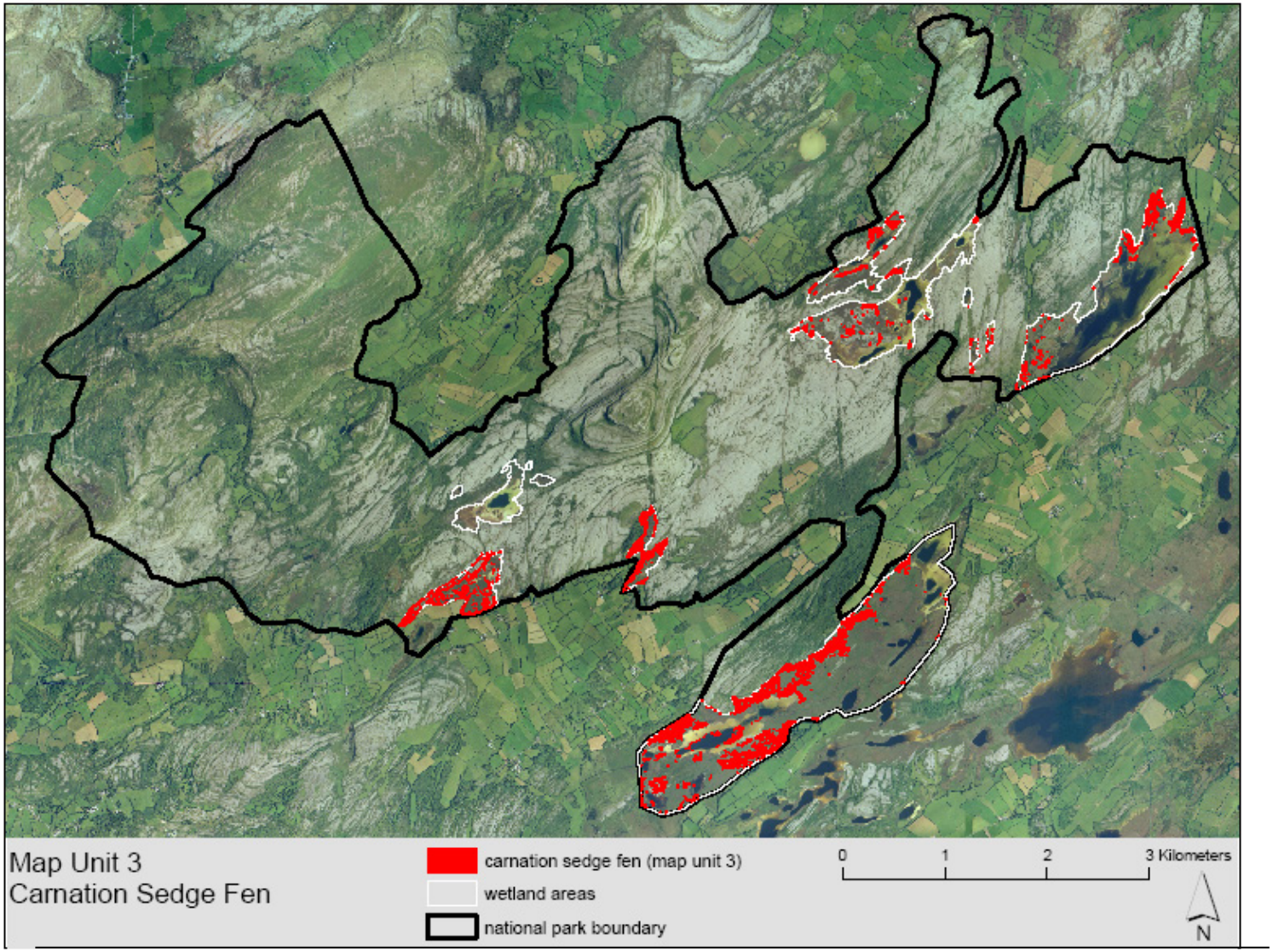


Figure 20. Distribution of the Carnation Sedge Fen community type (Map Unit 3) in sampled wetlands of Burren National Park.

Wetland Community Type 4. Black Bogrush Fen

Number of Relevés (n): 23

Dominant Plant Species: *Schoenus nigricans,*

Indicator Species: *Schoenus nigricans*

Species Richness: 10.1 ± 4.6 species/4 m^2, Range: 3-24 species.

Physiognomy: Herbaceous fen.

Relative Elevation and Hydrology: Occurs at intermediate relative elevations (2.3±0.7), and moderately high Water Depth Class (2.5±0.7)

Soil: Discontinuous, with moderately high organic content, mildly alkaline (Organic matter = 45.1 ± 22.0%; pH= 7.4 ± 0.7; marl present in 39% of samples, Litter Depth= 5.4 ± 5.8 cm)

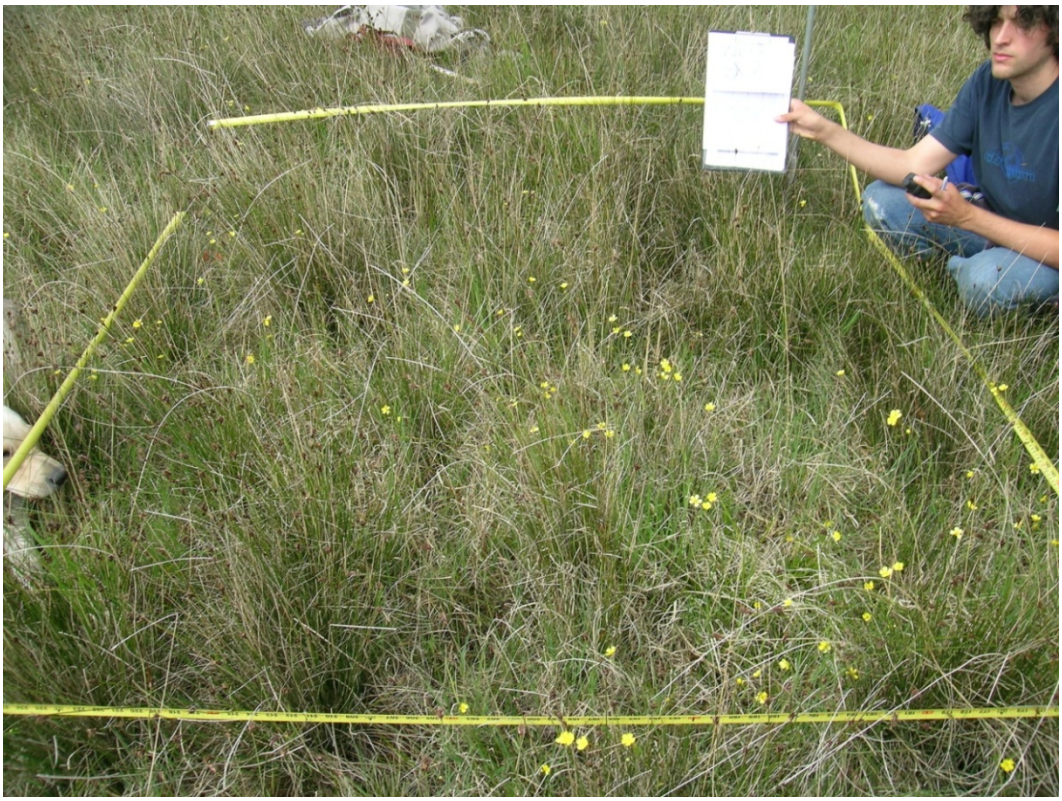
Biomass: Biomass Index = 9.5±4.5; Biomass (Dry Weight) Estimate= 1120.0±663.0 gm/m^2

Ground Cover: Total Vegetation Cover= 79.2%± 24.8%; Bare Ground= 10.9%± 22.0%; Exposed Rock=5.4% ± 12.6%; Litter= 16.1% ± 12.9%; Moss= 3.3% ± 3.3%;

Livestock Disturbance: Browsing= 0.0± 0.2; Poaching= 0.3± 0.9.

General Description: The Black Bogrush community type is the most common fen type in the park. It usually occurs at intermediate relative elevations, at similar or slightly higher relative elevations than the Carnation Sedge community type, but the two types are poorly differentiated hydrologically. The Black Bogrush community type has higher biomass and lower species richness than the Carnation Sedge Type. Black bogrush occurs in all stands, usually with purple moor grass, and often with carnation sedge, tawny sedge, or little green sedge. Forbs are less diverse and prominent than in the Carnation Sedge community type, but and include many of the same species. Hummocky topography allows presence of upland species such as bird's foot trefoil and emergent aquatic species, such as bog bean (*Menyanthes trifoliata*) to occur in close proximity. Occasional, but striking orchids including early marsh orchid (*Dactylorhiza incarnata*) and lesser butterfly-orchid (*Platanthera bifolia*) occur in spring. In the Ballyeighter Fen Complex, this type occurs contiguous to the Raised Bog community type, especially where turf cutting has lowered the peat surface enough to allow contact with calcareous groundwater. Livestock utilization appears to be much lower in this type than in sedge-dominated types, and a well developed thatch layer is characteristic.

a.



b.



Figure 21. Overview of Black Bogrush community type: a) View of sample relevé, b) overview showing zonation from edge towards center of Lough Aughrim wetland. Note transition from Black Bogrush type in foreground to Carnation Sedge type in background.

a.



b.



c.



Figure 22. Common wetland plants of the Black Bogrush community type: a) black bogrush (*Schoenus nigricans),* b) early marsh orchid (*Dactylorhiza incarnata*), c) lesser butterfly orchid (*Platanthera bifolia*).

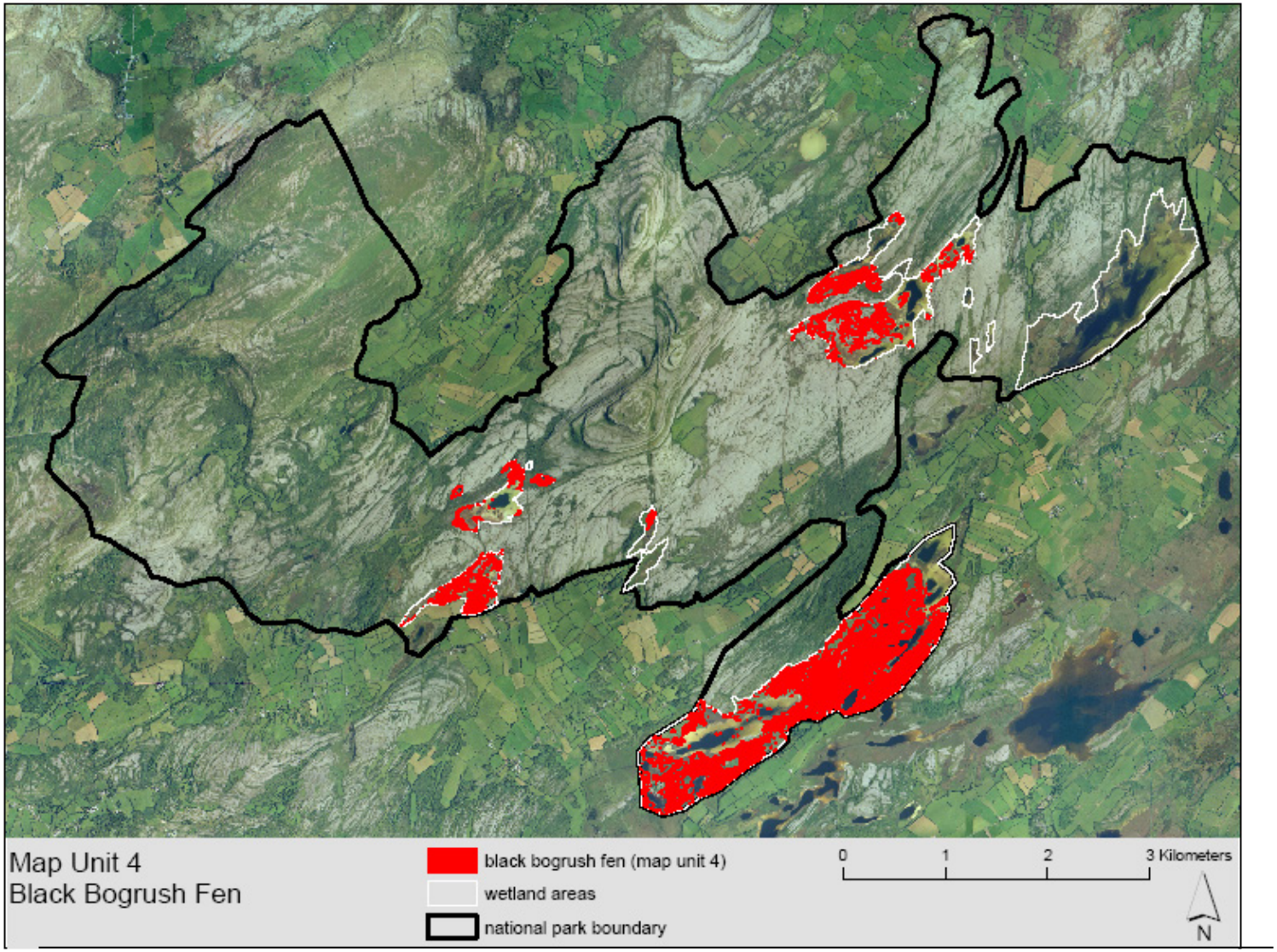


Figure 23. Distribution of the Black Bogrush Fen community type (Map Unit 4) in sampled wetlands of Burren National Park.

Wetland Community Type 5. Wet Sedge-Horsetail Fen and Flush

Number of Relevés (n): 7

Dominant Plant Species: *Carex nigra, Carex vesicaria, Eleocharis palustris*

Indicator Species: *Caltha palustris, Mentha aquatica, Ranunculus* spp.

Species Richness: 13.6 ± 3.6 species/4 m^2, Range: 10-20 species.

Physiognomy: Herbaceous meadow.

Relative Elevation and Hydrology: Occurs at intermediate relative elevations (2.0±0.8), and moderate Water Depth Class (2.3±0.8)

Soil: Moderately high organic content, neutral (Organic matter = 37.8 ± 19.4%; pH= 7.1 ± 0.6; marl present in 43% of samples, Litter Depth= 1.4 ± 1.0 cm)

Biomass: Biomass Index = 7.3±5.4; Biomass (Dry Weight) Estimate= 845.2±711.5 gm/m^2

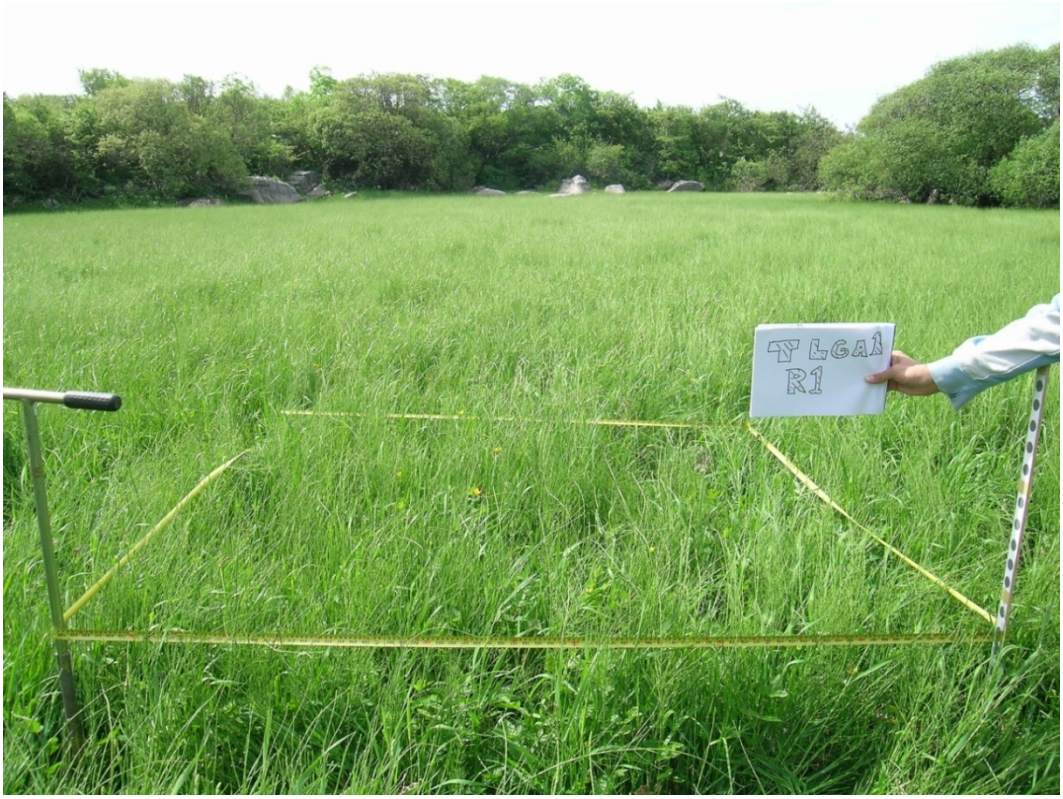
Ground Cover: Total Vegetation Cover= 89.3%± 12.3%; Bare Ground= 4.3%± 6.1%; Exposed Rock=2.1% ± 5.7%; Litter= 2.9% ± 2.7%; Moss= 0.9% ± 1.6%;

Livestock Disturbance: Browsing= 1.7± 1.8; Poaching= 1.6± 1.8.

General Description:

The Wet Sedge-Horsetail Fen and Flush community type occurs in small basins where water levels are at or above the soil surface for extended periods (Figure 24a) or along shallow channels within drier fen types and turloughs, (Figure 24b), especially around turlough outlets (Figure 25f). These sites are quite variable in vegetation, but typically contain both higher proportions of forb and reedswamp vegetation than the more extensive fen types. The vegetation is characterized by a variety of graminoid species, including common sedge (*Carex nigra*), inflated sedge (*Carex vesicaria*), common spike rush (*Eleocharis palustris*), and sometimes scattered reed (*Phragmites australis*), often co-dominating with common horsetail (*Equisetum arvensis*). A subordinate but more characteristic array of semiaquatic forbs, including marsh marigold (*Caltha palustris*), water mint, spearwort (*Ranunculus flammula*), and other buttercup species also occur. Other associates include marsh pennywort, brookweed, bedstraw (*Galium uliginosum*), and mare's tail (*Hippuris vulgaris*).

a.



b.



Figure 24. Overviews of sample relevés in relatively a) ungrazed and b) grazed, poached conditions.

a.  b. 

c.  d. 

e.  f. 

Figure 25. Common vascular plants of the Wet Sedge Fen and Flush community type: a) common spikerush (*Eleocharis palustris*), b) lesser spearwort (*Ranunculus flammula*), c) marsh marigold (*Caltha palustris*), d) inflated sedge (*Carex vesicaria*), e) horsetail (*Equisetum arvense*) with lesser spearwort and marsh marigold, f) mare's tail (*Hippuris vulgaris*) in sinkhole.

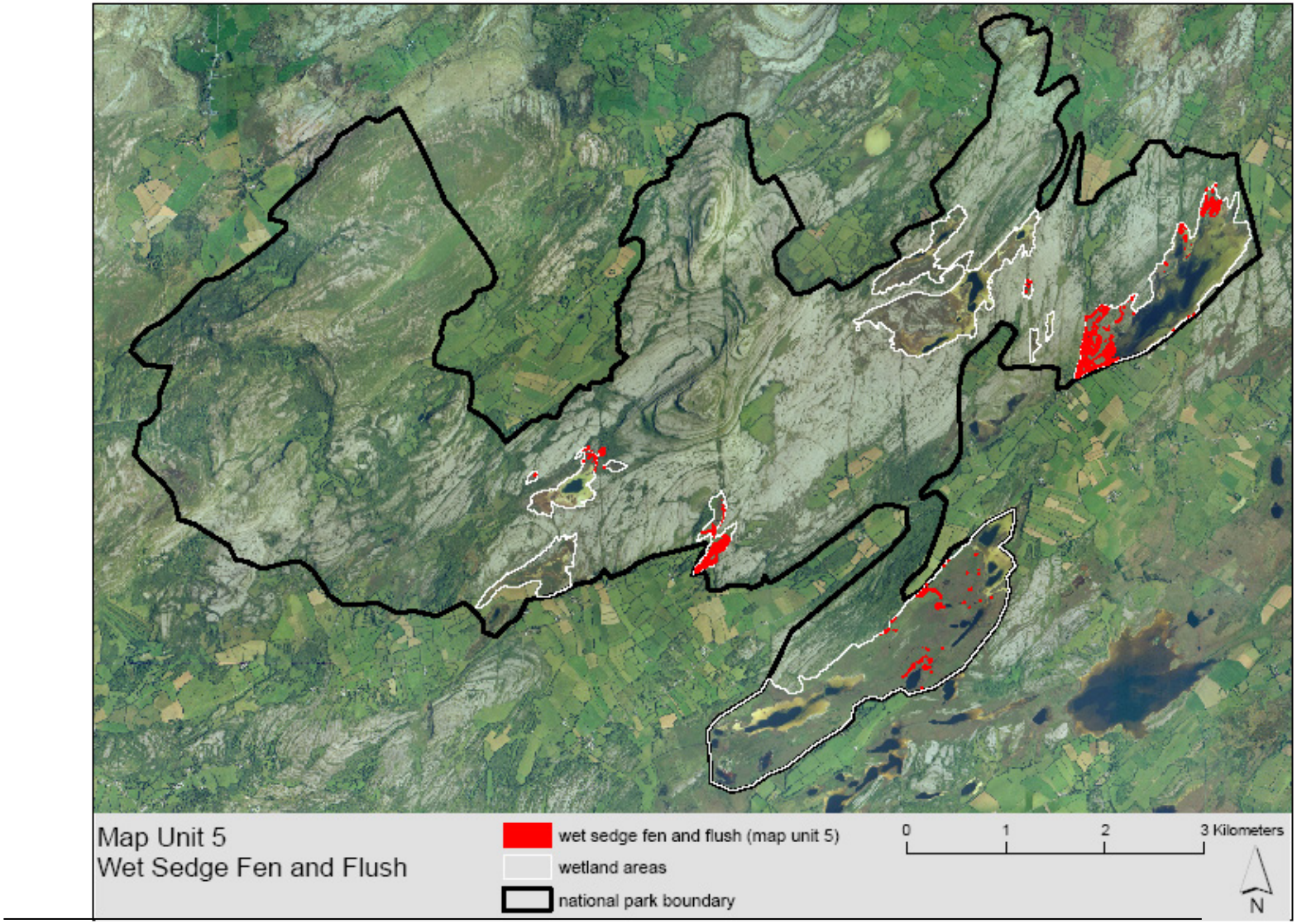


Figure 26. Distribution of the Wet Sedge Fen and Flush community type (Map Unit 5) in sampled wetlands of Burren National Park.

Wetland Community Type 6. Turlough Floor Meadow

Number of Relevés (n): 11

Dominant Plant Species: *Carex viridula, Carex elata*

Indicator Species: *Carex viridula*

Species Richness: 9.6 ± 3.6 species/4 m^2, Range: 6-16 species.

Physiognomy: Herbaceous meadow.

Relative Elevation and Hydrology: Occurs at low relative elevations (1.8±0.6), and but high Water Depth Class (2.5±0.8)

Soil: Low organic content, highly alkaline (Organic matter = 20.6 ± 16.1%; pH= 7.7 ± 0.2; marl present in 73% of samples, Litter Depth= 1.4 ± 1.5 cm)

Biomass: Biomass Index = 4.0±3.5; Biomass (Dry Weight) Estimate= 375.7±269.8 gm/m^2

Ground Cover: Total Vegetation Cover= 77.1%± 21.0%; Bare Ground= 10.7%± 14.7%; Exposed Rock=0.6% ± 1.6%; Litter= 12.9% ± 17.4%; Moss= 5.1% ± 6.1%;

Livestock Disturbance: Browsing= 0.2± 0.6; Poaching= 1.6± 1.8.

General Description: The Turlough Floor Meadow community type is typically a somewhat sparse herbaceous community that occurs within turlough basins of the park, usually abutting sparsely vegetated marl lakes or dry marl flats. Little green sedge (*Carex viridula*) is the most characteristic species of this type, indicating long inundation and marly lacustrine soils. Robust stands of tufted sedge (*Carex elata*) often form a discontinuous canopy, where water is ponded later in the year. Thus, the biomass of this type is extremely variable, but typically low. When dry the vegetation often is covered with marl deposition, giving it a yellow cast. The transitional nature of the type is evidenced by much floristic overlap with the Wet Sedge-Horsetail Fen and Flush and Marl Flat community types. Other common graminoids include many-stemmed spikerush (*Eleocharis multicaulis*), jointed rush (*Juncus articulatus*), common sedge (*Carex nigra*), and carnation sedge (*C. panicea*). Forb associates include lesser spearwort (*Ranunculus flammula*), lesser water-plantain (*Baldellia ranunculoides*), and brookweed (*Samolus valerandi*). Dead and marl-encrusted aquatics, such as rigid hornwort (*Ceratophyllum demersum*) can often be seen covering the ground surface during the dry season.

a.



b.

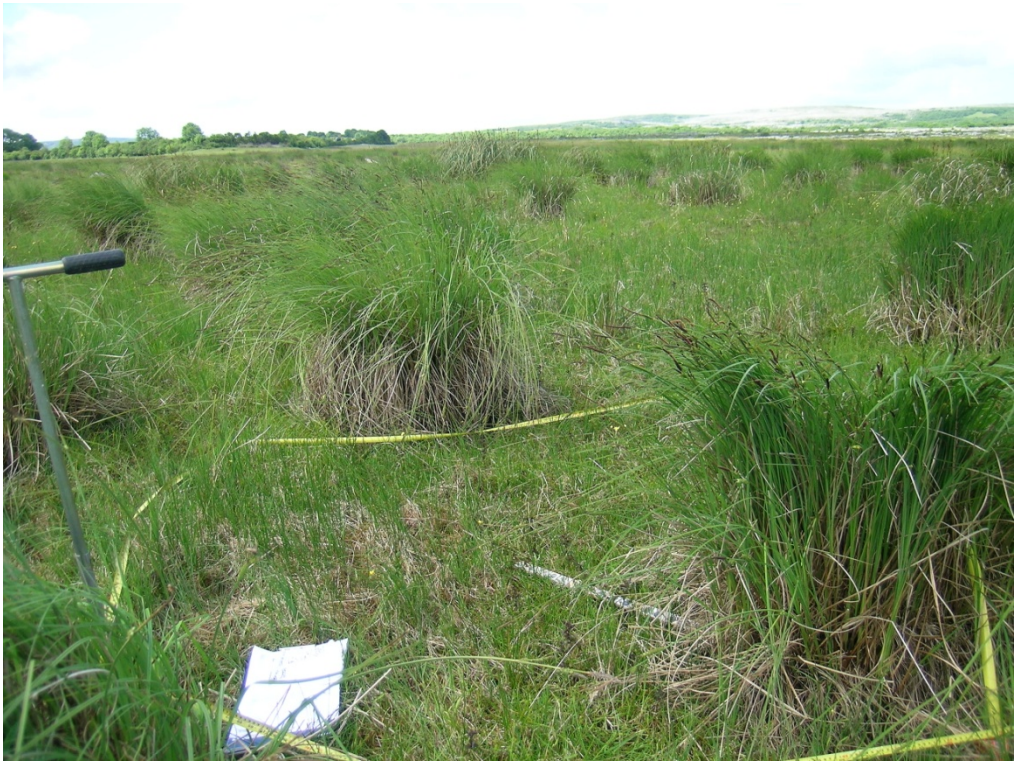


Figure 27. Overviews of sampling relevés in Turlough Floor community type: a) marl encrusted yellow sedge (*Carex viridula*) and carnation sedge (*Carex panicea*) in Coolorta Turlough, b) type with diffuse stand of tufted sedge (*Carex elata*) in Knockanroe Turlough.

a. 

b. 

Figure 28. Characteristic vascular plants of Turlough Floor community type: a) little yellow sedge (*Carex viridula*), b) tufted sedge (*Carex elata*).

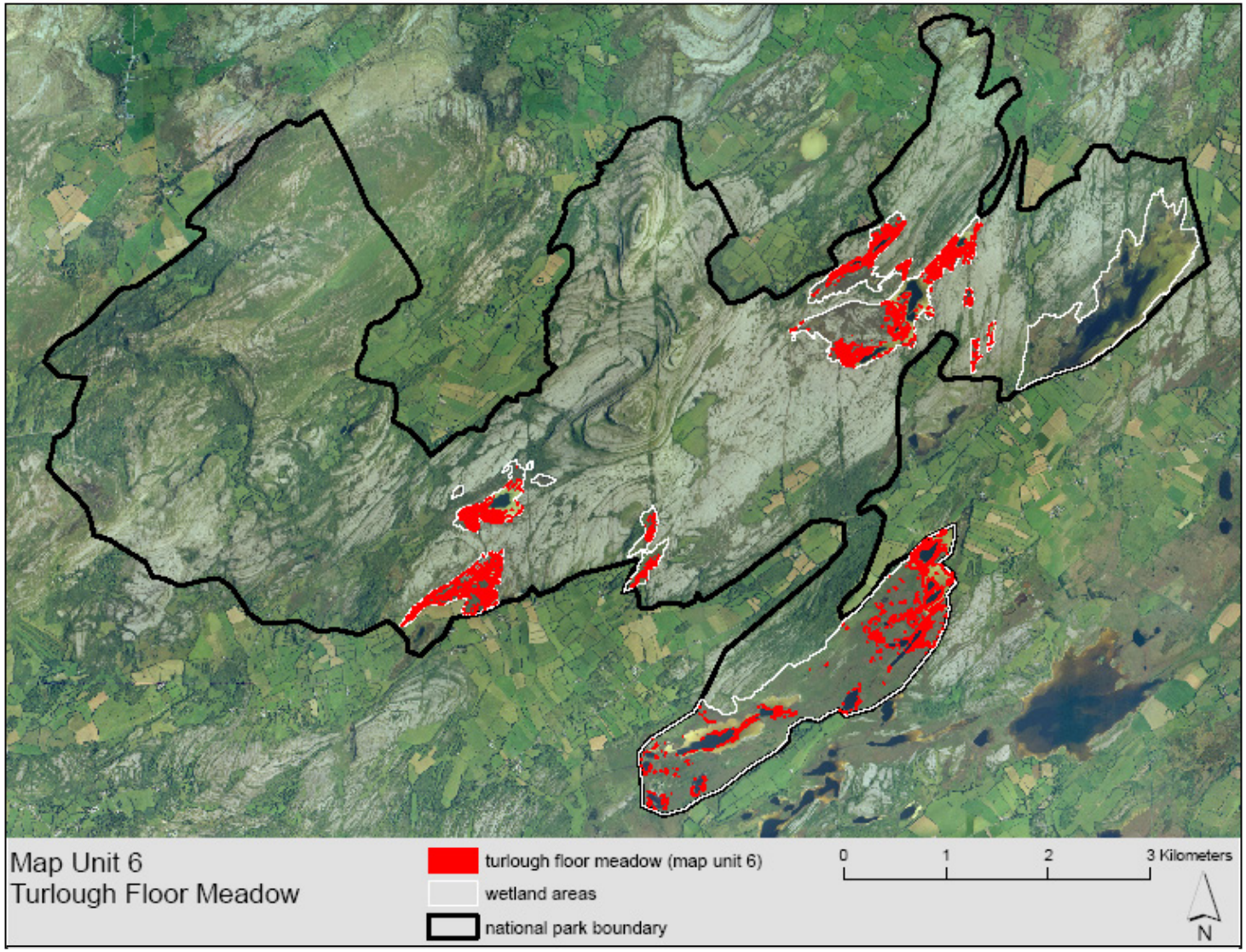


Figure 29. Distribution of the Turlough Floor community type (Map Unit 6) in sampled wetlands of Burren National Park.

A. Semipermanently- and Permanently-Flooded, Lower Wetland Communities

Wetland Community Type 7. Sawsedge Fen

Number of Relevés (n): 10

Dominant Plant Species: *Cladium mariscus*

Indicator Species: *Cladium mariscus*

Species Richness: 4.3 ± 2.4 species/4 m^2, Range: 3-9 species.

Physiognomy: Herbaceous meadow.

Relative Elevation and Hydrology: Occurs at low relative elevations (1.2±0.4), and shallow Water Depth Class (1.4±0.5)

Soil: Peaty with high organic content, neutral (Organic matter = 56.4 ± 25.6%; pH= 7.0 ± 0.4; marl present in 20% of samples, Litter Depth= 26.5 ± 16.2 cm)

Biomass: Biomass Index = 18.5±2.1; Biomass (Dry Weight) Estimate= 5038.5±1462.3 gm/m^2

Ground Cover: Total Vegetation Cover= 70.5%± 12.4%; Bare Ground= 3.4%± 9.4%; Exposed Rock=0.1% ± 0.2%; Litter= 31.0% ± 11.3%; Moss= 0.2% ± 0.4%;

Livestock Disturbance: Browsing= 0.0± 0.0; Poaching= 0.0± 0.0.

General Description:

The Sawsedge Fen community type is the most characteristic wetland plant community in Burren National Park. Extensive fens occur around most of the turloughs and limestone lakes, wherever groundwater flows from fractured limestone. Stands of this type are often two to three meters in height, with very high biomass and low species richness. Sawsedge (*Cladium mariscus*) is strongly dominant in nearly all stands, with scattered reed, and less frequently bulrush (*Schoenoplectus lacustris*) co-occurring. The semi-aquatic birdfoot trefoil (*Menyanthes trifoliata*) is the only commonly occurring understory species, though bladderwort (*Utricularia* spp.) is sometimes present. In turloughs, this type occurs in association with the Turlough Floor Meadow community type, and tufted sedge (*Carex elata*) may be an important associate. The cover of the standing vegetation rarely exceeds 90%, yet a dense and thick litter layer leaves little growing space for a ground layer. This type does not appear to be palatable to livestock and browsing and poaching are minimal.

a.



b.



Figure 30. Views of Sawsedge Fen community type: a) field assistant in Sawsedge (*Cladium mariscus*) Fen community type, b) dense stand of Sawsedge Fen Community Type at Aughrim Ponds wetland (background; Turlough Floor Meadow with tufted sedge in foreground).

a.



b.



c.



Figure 31. Characteristic plants of the Sawsedge Fen community type: a) sawsedge (*Cladium mariscus*), b) bogbean (*Menyanthes trifoliata*), c) lesser bladderwort (*Utricularia minor*).

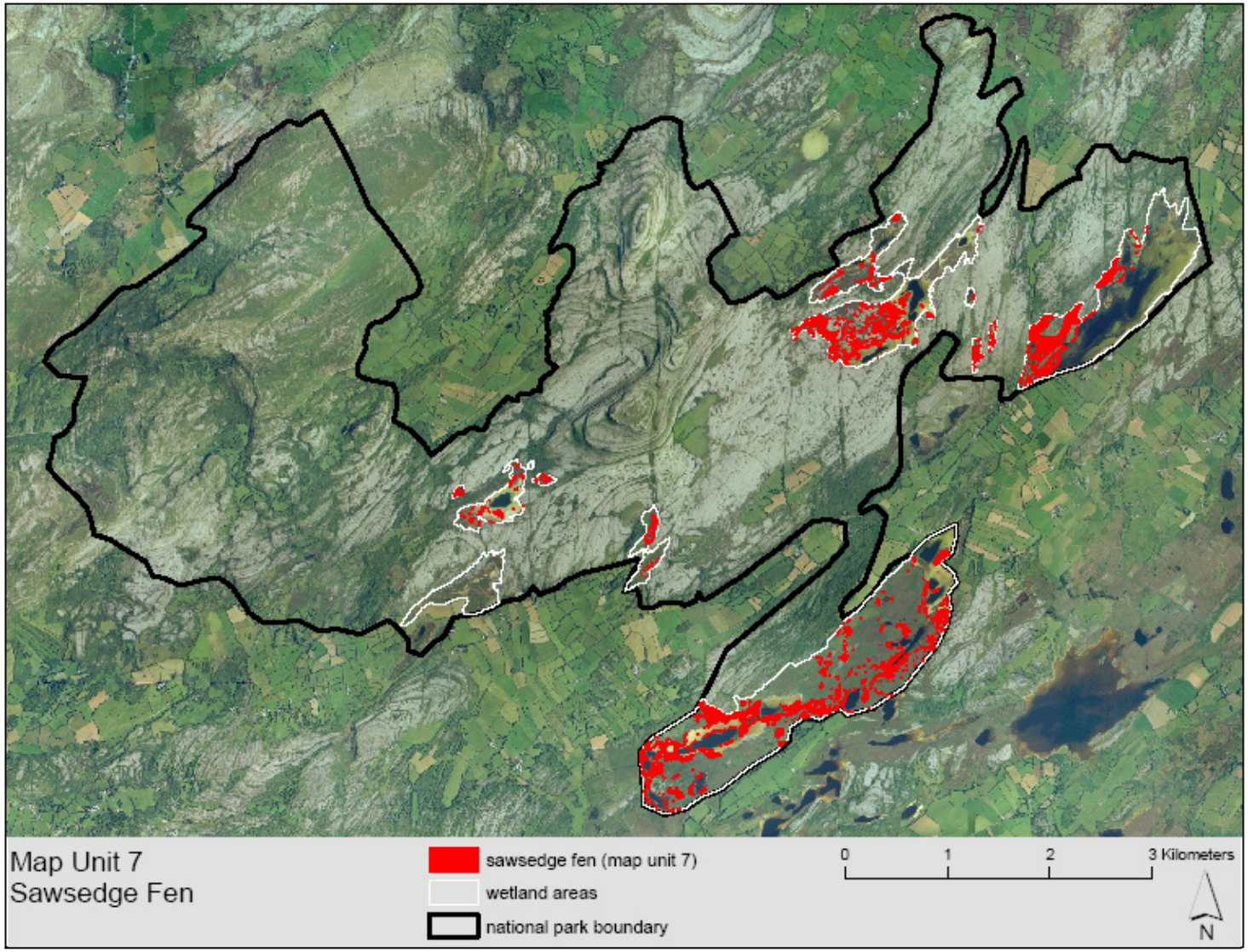


Figure 32. Distribution of the Sawsedge Fen community type (Map Unit 7) in sampled wetlands of Burren National Park.

Wetland Community Type 8. Bulrush-Common Reed Reedswamp

Number of Relevés (n): 6

Dominant Plant Species: *Schoenoplectus lacustris, Phragmites australis*

Indicator Species: *Schoenoplectus lacustris*

Species Richness: 7.8 ± 4.0 species/4 m^2, Range: 3-13 species.

Physiognomy: Sparse emergent reedswamp.

Relative Elevation and Hydrology: Occurs at lowest relative elevations (1.2±0.6), and has shallow Water Depth Class (1.7±0.8)

Soil: Marl lake bottoms with low organic content, mildly alkaline (Organic matter = 17.4 ± 9.3%; pH= 7.3 ± 0.2; marl present in 83% of samples, Litter Depth= 1.0 ± 1.3 cm)

Biomass: Biomass Index = 5.0±6.2; Biomass (Dry Weight) Estimate= 844.1±1476.4 gm/m^2

Ground Cover: Total Vegetation Cover= 57.8%± 23.5%; Bare Ground= 36.7%± 30.3%; Exposed Rock=1.0% ± 2.5%; Litter= 13.3% ± 19.7%; Moss= 0.0% ± 0.0%;

Livestock Disturbance: Browsing= 0.0± 0.0; Poaching= 1.2± 0.4.

General Description: The Bulrush-CommonReed Reedswamp community type is the primary form of reedswamp vegetation occurring around the edges of marl-bottomed lakes in Burren National Park. In most cases these are emergent plant communities with water above the soil surface through the entire growing season, the type is often seen in depauperate form around the edges of some turlough inlets, where water may drop below the soil surface in summer. Generally, bulrush (*Schoenoplectis lacustris*) is more dominant in areas with the most reliable water, such around the edges of dolines within the larger shallow lake basins. Common reed (*Phragmites australis*) occurs around the shallower edges of the lake basins were desiccation occurs at least occasionally. The vegetation is rank, often exceeding 1.5 m in height, but surprisingly sparse in most of the marl lakes. Besides bulrush and common reed, other aquatic species, such as hornwort (*Ceratophyllum demersum*), bird's foot trefoil (*Menyanthes trifoliata*), white pond lily (*Nymphaea alba*), and pondweed (*Potamogeton gramineus*) are occasional associates. Slender sedge (*Carex lasiocarpa*), shoreweed (*Litorella uniflora*) and many-stalked spikerush (*Eleocharis multicaulis*) may occur around the edges of lakes on pure marl. Where surface waters recede for at least part of the growing season, many species from the Turlough Floor Meadow and Wet Sedge Fen and Flush Types occur, including tufted sedge (*Carex elata*), little green sedge (*C. viridula*), common sedge (*C. nigra*), lesser water-plantain (*Baldellia ranunculoides*), and lesser spearwort (*Ranunculus flammula*).

a. 

b. 

Figure 33. Views of Bulrush-Common Reed Reedswamp community type: a) oblique view of Bulrush-Common Reed Reedswamp Community type at Skaghard Lough (note sparse common reed (Phragmites australis) in foreground and denser bulrush (Schoenoplectus lacustris) in background at edge of central pond, b) near view of sparse Bulrush-Common Reed Reedswamp community type at Lough Bunny.

a. 

b. 

Figure 34. Views of Dense Bulrush-Common Reed Reedswamp community type in Lough Awaddy: a) dense stands of common reed (*Phragmites australis*), b) sampling relevé view in bulrush (*Schoenoplectus lacustris*).

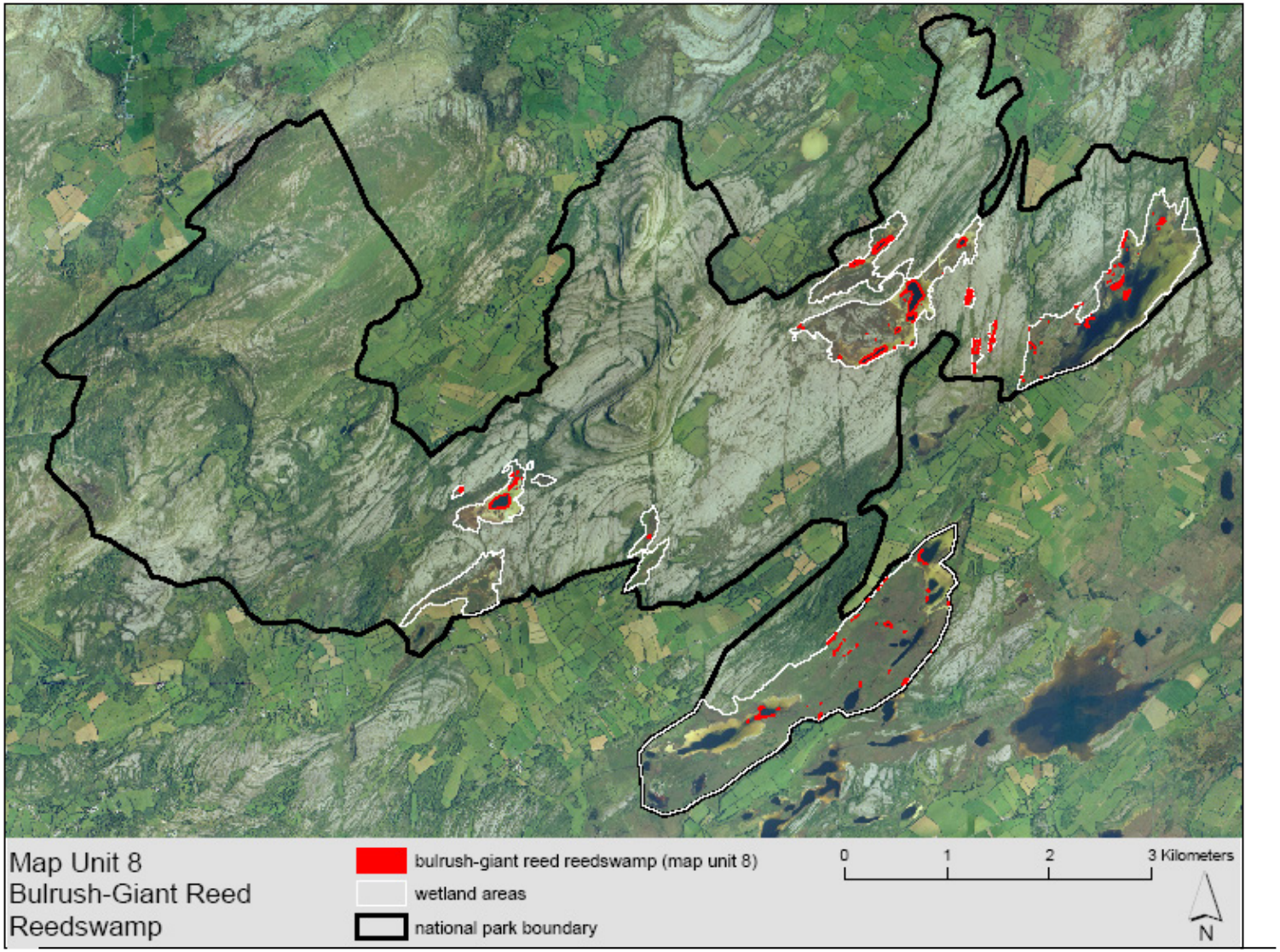


Figure 35. Distribution of the Bulrush-Common Reed Reedswamp community type (Map Unit 8) in sampled wetlands of Burren National Park.

Wetland Community Type 9. Sparsely Vegetated Marl Flat

Number of Relevés (n): 8

Dominant Plant Species: *Littorella uniflora, Eleocharis multicaulis*

Indicator Species: *Littorella uniflora*

Species Richness: 2.9 ± 0.8 species/4 m^2, Range: 2-4 species.

Physiognomy: Sparse herbaceous

Relative Elevation and Hydrology: Occurs at lowest relative elevations (1.0±0.0), and moderate Water Depth Class (2.1±1.0)

Soil: Low organic content, highly alkaline (Organic matter = 18.7 ± 15.4%; pH= 7.8 ± 0.3; marl present in 100% of samples, Litter Depth= 0.0 ± 0.0 cm)

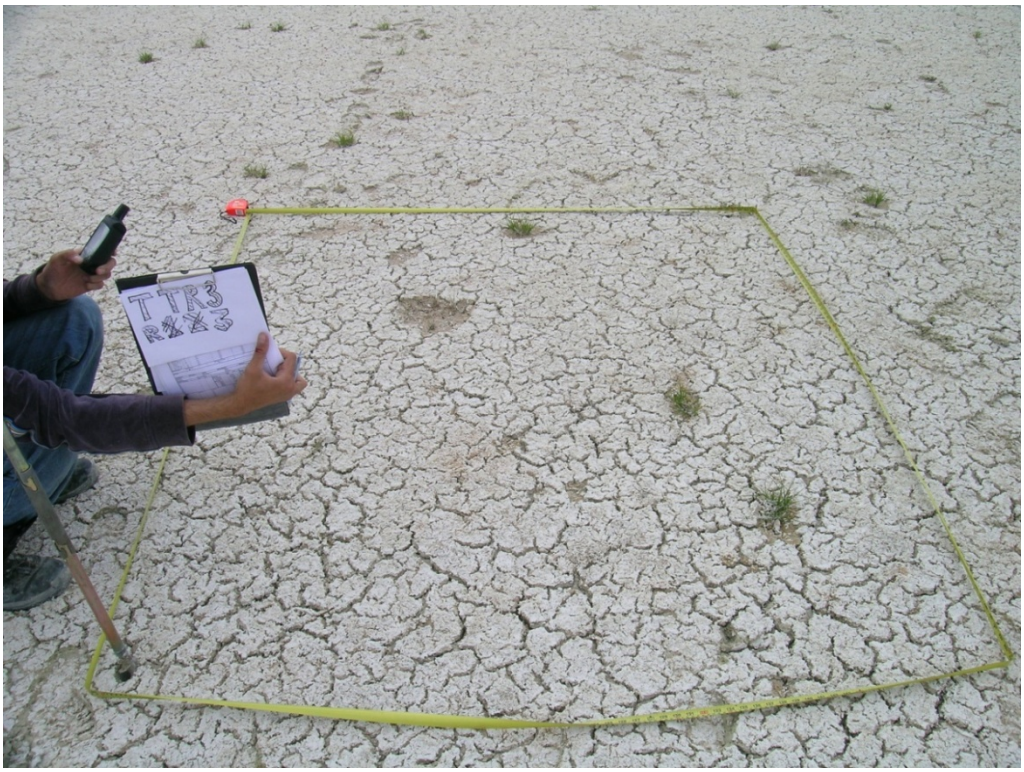
Biomass: Biomass Index = 0.1±0.3; Biomass (Dry Weight) Estimate= 148.1±8.2 gm/m^2

Ground Cover: Total Vegetation Cover= 11.6%± 15.5%; Bare Ground= 84.3%± 13.2%; Exposed Rock=4.4% ± 10.5%; Litter= 3.8% ± 8.8%; Moss= 0.7% ± 1.8%;

Livestock Disturbance: Browsing= 0.0± 0.0; Poaching= 0.0± 0.0.

General Description: The Sparsely Vegetated Marl Flat community type lies at the floor of turloughs, immediately downslope from the Turlough Floor Meadow community type. It may also abut the Bulrush-Common Reed Reedswamp community type where standing water remains through the growing season. This is the most species poor of the types with a sparse cover of shoreweed (*Littorella uniflora*), often with many-stalked spikerush (*Eleocharis multicaulis*). The vegetation is typically confined to the edges of the marl flats with extensive unvegetated areas over the lowest portions of the turlough floor. These sites are inundated for long periods each year to several meters depth, but dry out for a period in spring and summer in most years. Substrate is almost pure marl of a claylike textured, drying to a cracking crust in summer.

a.



b.



Figure 36. Views of Sparsely Vegetated Marl Flat community type: a) sampling relevé view with scattered little green sedge (*Carex viridula*), b) oblique view with shoreweed (*Littorela uniflora*) and many stemmed spike rush (*Eleocharis multicaulis*). Both photos taken in Coolorta Turlough.

a.



b.



c.



Figure 37. Context and characteristic vascular plants of the Turlough Floor community type: a) oblique view at Lough Gealáin showing zonation from Black Bogrush (right) to Turlough Floor Meadow (middle) to Sparsely Vegetation Marl Flat (left), b) shoreweed (*Littorella uniflora*), c) many stalked spikerush (*Eleocharis multicaulis*).

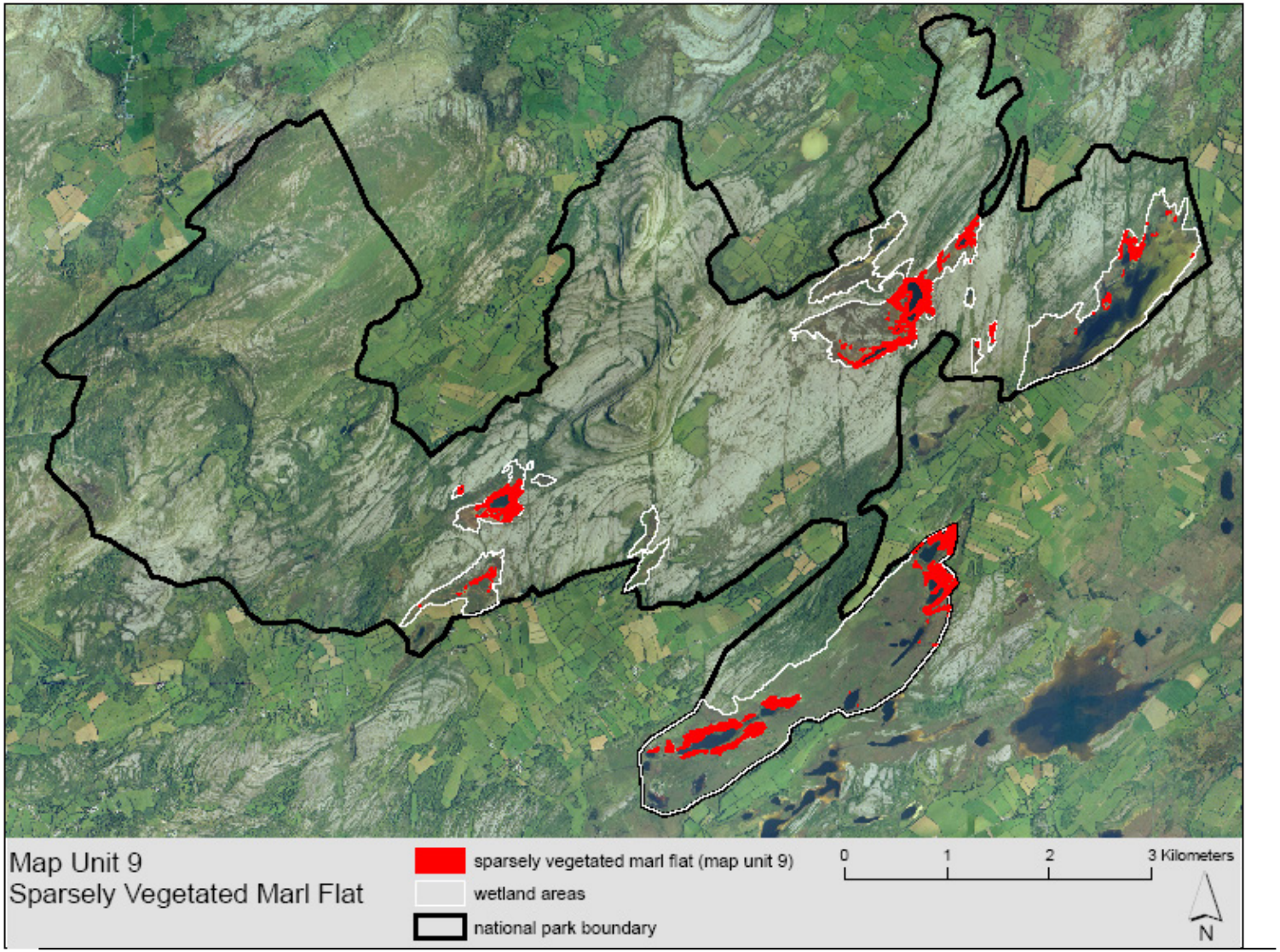


Figure 38. Distribution of the Sparsely Vegetated Marl Flat community type (Map Unit 9) in sampled wetlands of Burren National Park.

Major Wetland Complexes of the Burren National Park

For a relatively small national park, the BNP contains a surprisingly rich array of wetlands, and they tend to be clustered in several wetland complexes which vary in community composition and in the spatial pattern of the plant communities present. In this section we describe several of the wetland complexes in the park. The intent is to provide a narrative description of the wetland, relative proportions of the plant communities present, and other biophysical observations made during the survey.

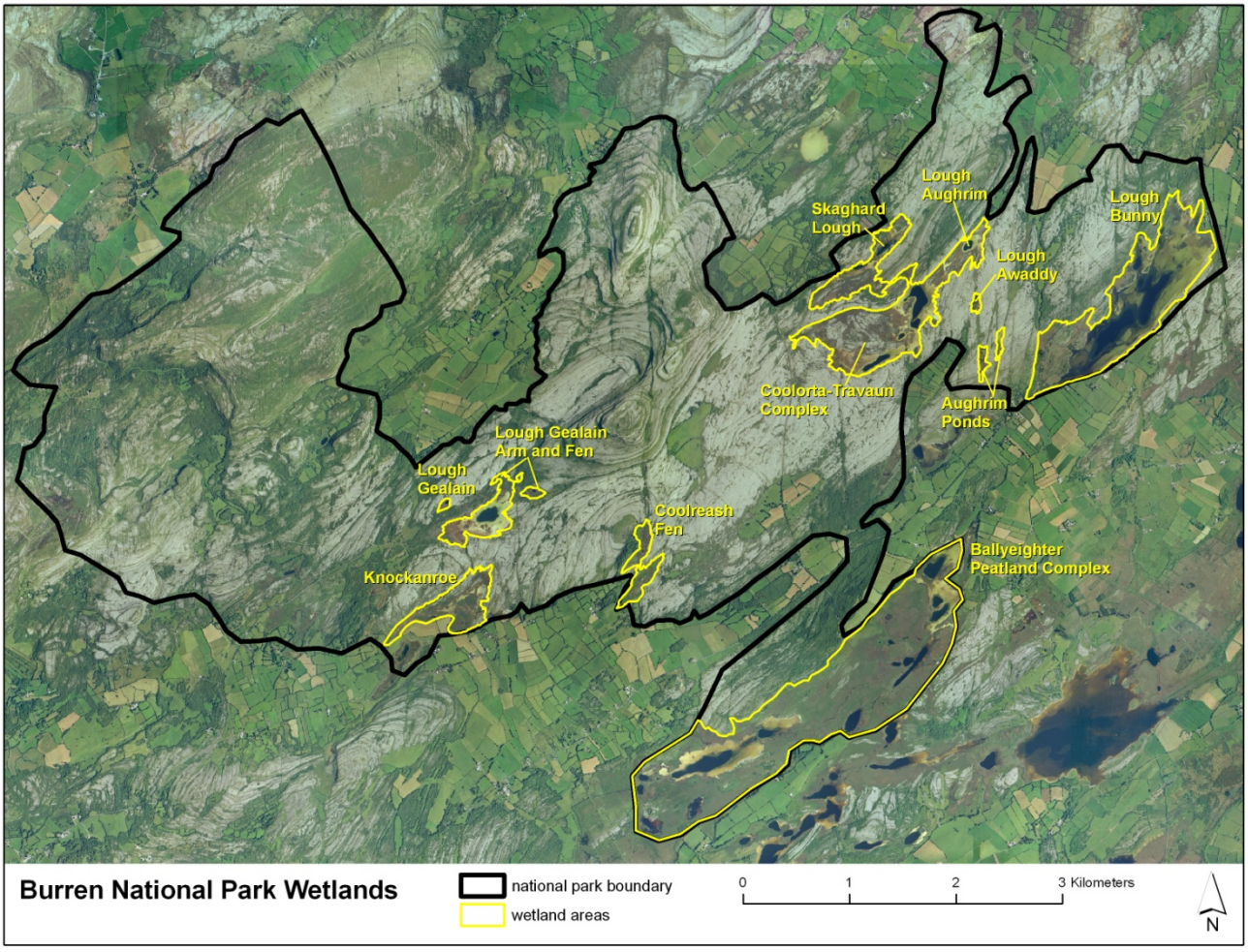


Figure 39. Major wetland complexes of Burren National Park.

Ballyeighter Peatland

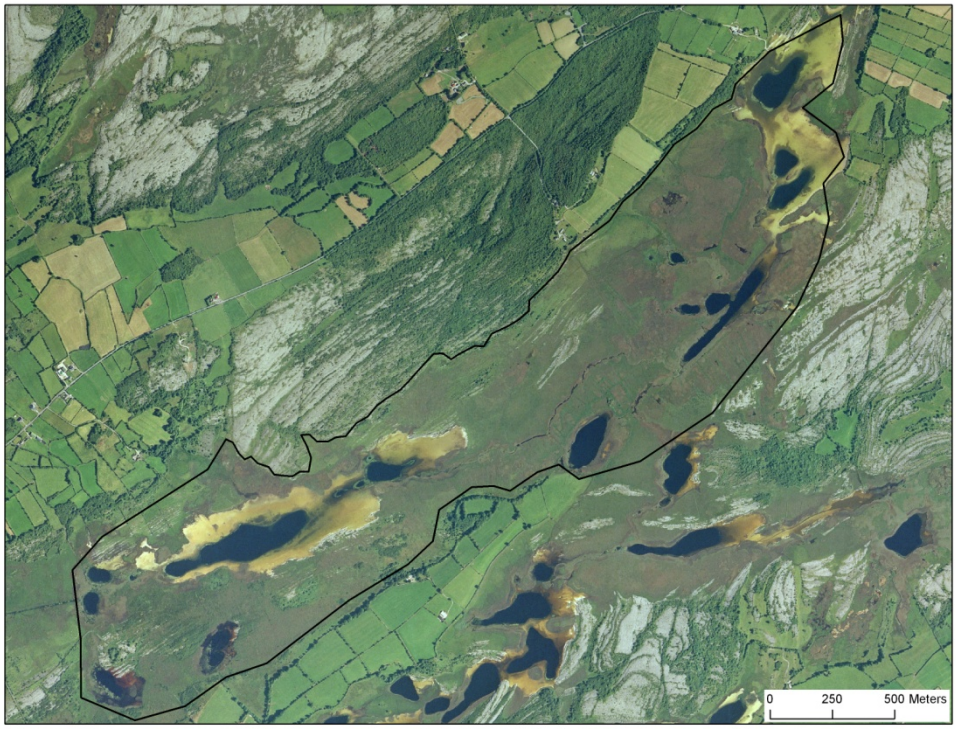
Bally Eighter Peatland is a bog and fen complex at lowest elevations along the southern edge of the park. It is by far the most extensive peat body in the park and environs, reflecting favorable hydrology for peat formation over a long period. Soils of the highest peat surfaces, which are the residual ridges of the original peat body have notably lower pH than the rest of the complex and are marked by stands of bog myrtle and other calcifuge species of the Raised Bog community type, which covers under five percent of the total area. Most of the wetland surface is cutover peat, and therefore in contact with the highly alkaline groundwater. Such areas are dominated by either Black Bogrush or Sawsedge community types, occupying 43.5% and 10.3% of the wetland area, respectively (Table 2). Several shallow marl lakes are scattered through the wetland. Evidence of peat erosion is common at the southwestern most lake margin, suggesting that wind erosion is important, leaving exposed marl and limestone flats. Several exposed limestone reefs rise out of the peatland forming islands of distinctive flora in the midst of the more widespread wetland types.

During the time of our visit (May-June 2008), livestock appeared to have closely cropped most of the sedge fen types, especially on the northern edges, with abundant evidence of trampling in the wettest areas. Species richness was very high in such sites with some relevés exceeding 25 vascular plant species.

Table 2. Wetland composition of Ballyeighter peatland complex.

Map Unit	Type Name	Hectares	Percent of Wetland area
0	upland	10.10	3.90
1	raised bog	10.70	4.14
2	limestone	10.61	4.10
3	carnation sedge fen	24.81	9.59
4	black bogrush fen	112.59	43.52
5	wet sedge fen and flush	1.87	0.72
6	turlough floor meadow	16.98	6.56
7	sawsedge fen	26.51	10.25
8	bulrush- reed reedswamp	1.30	0.50
9	sparsely vegetated marl flat	22.22	8.59
10	open water	21.04	8.13
	total area (ha)	258.72	100.0

a.



b.

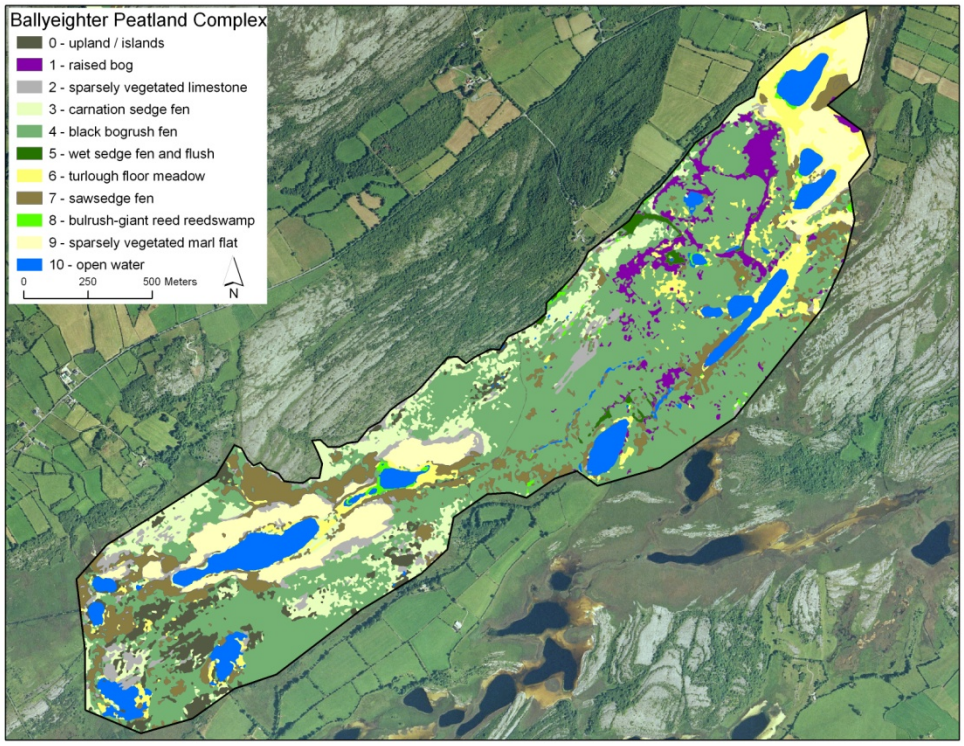


Figure 40 a.) Ballyeighter Peatland complex, b) distribution of mapping units in the Ballyeighter Peatland complex.

Skaghard-Coolorta-Trauvaun-Aughrim Wetland Complex

Skaghard-Coolorta-Trauvaun-Aughrim Wetland Complex is perhaps the most heterogeneous wetland complex in the park, containing over 100 hectares of diverse wetland communities. It contains several interconnected wetland basins, which differ in character and species composition, grading from fen to lake to turlough habitats. Here, we present maps and summary statistics for two subcomplexes: 1) the Skaghard Lough subcomplex, and 2) the Coolorta-Travaun-Aughrim subcomplex.

Skaghard Lough Subcomplex

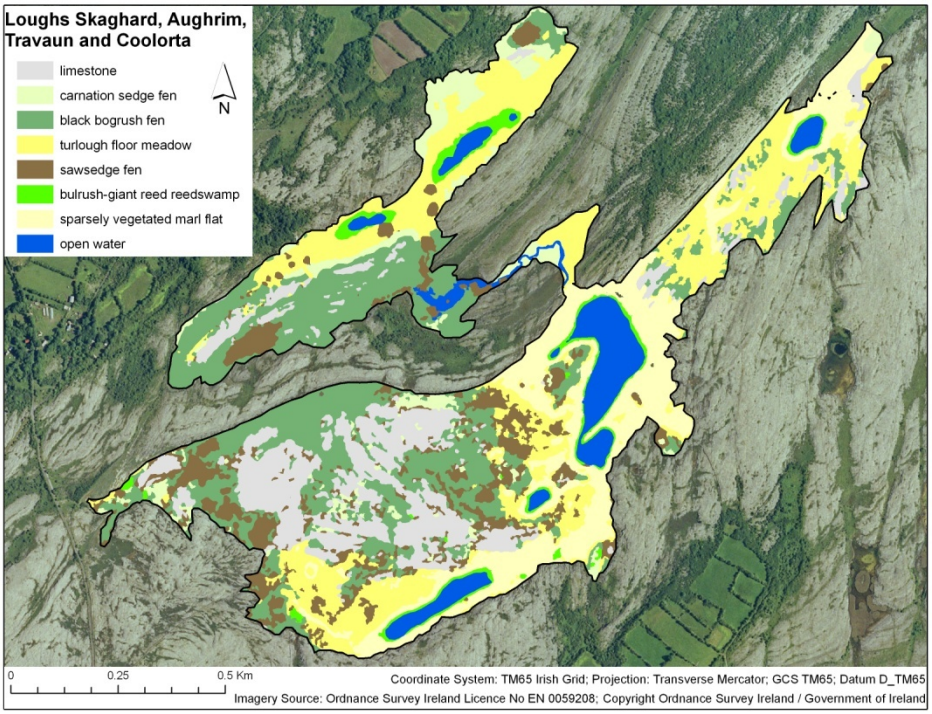
Skaghard Lough is the head of the Skaghard-Coolorta-Travaun-Aughrim wetland complex and serves as the source of much of the water flow into the other turlough basins through a shallow surface stream draining southward. Like Lough Gealáin, it is a complex turlough, with deepwater, reedswamp, and fen characteristics intermixed. Several deep basins in the midst of the wetland provide permanent deepwater habitat and are rimmed with largely bulrush. More extensive areas of the turlough floor support a sparse cover of reed, interspersed with bird's foot trefoil, and other semiaquatic species. Where the water exits to the south of the turlough basin, vegetation is largely Sawsedge and Black Bogrush Fen. This water course is an interesting complex in itself, with a mixture of flowing water and turlough and fen vegetation types. Black Bogrush Fen is the most extensive vegetation type by area (31.2%), followed by Turlough Floor Meadow (28.3%), Carnation Sedge Fen (11.6%), and Sawsedge Fen (7.2%; Table 3).

Table 3. Wetland composition of Skaghard Lough subcomplex of the Skaghard-Coolorta-Trauvaun-Aughrim wetland complex.

Map Unit	Type Name	Hectares	Percent of Wetland area
4	Black Bogrush Fen	8.45	31.21
8	Bulrush-Reed Reedswamp	0.93	3.45
3	Carnation Sedge Fen	3.15	11.61
2	Sparsely Vegetated Limestone	3.57	13.19
10	Open Water	1.35	5.00
7	Sawsedge Fen	1.95	7.21
6	Turlough Floor Meadow	7.68	28.34
	Total Area (ha)	27.09	100.0

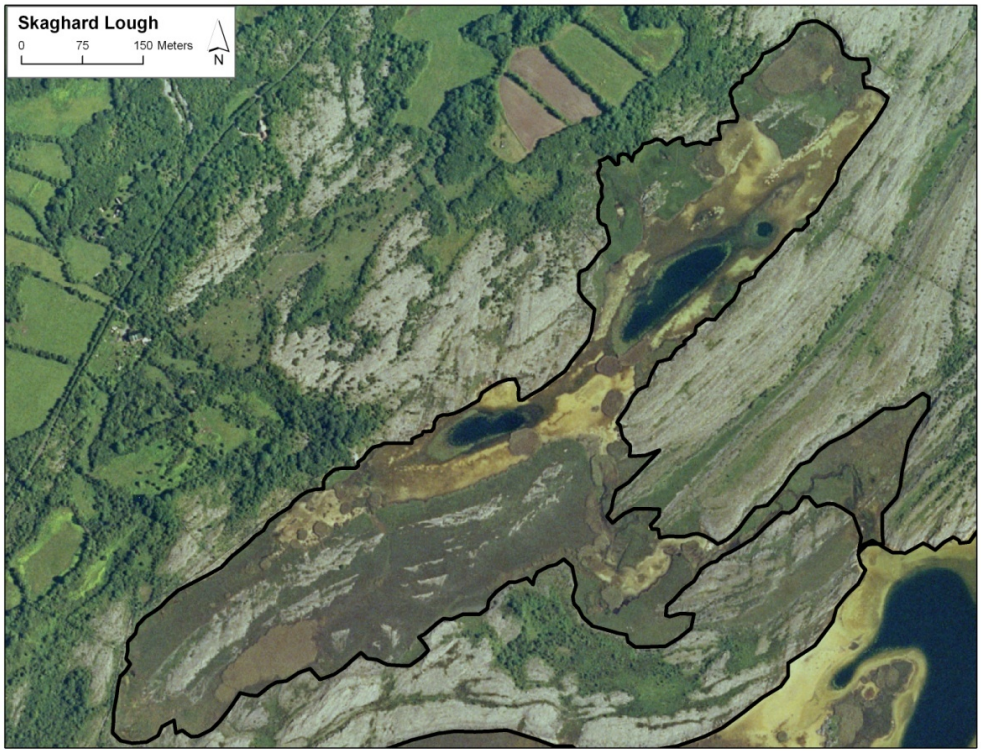


a.

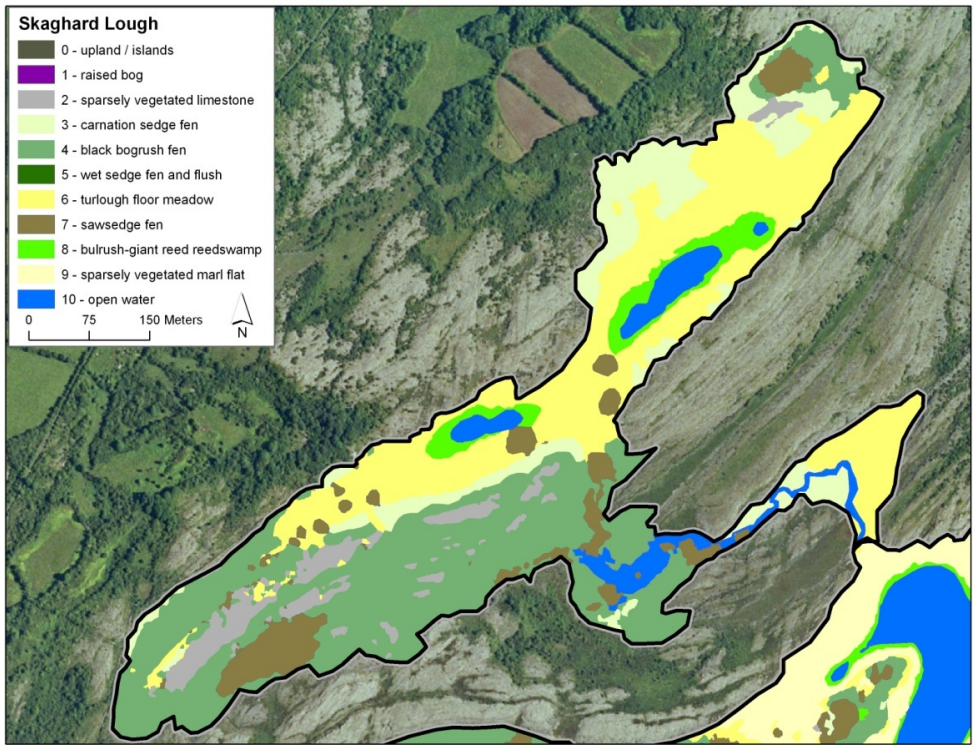


b.

Figure 41. Skaghard-Coolorta-Trauvaun-Aughrim wetland complex: a) orthophoto of wetland, b) distribution of wetlands mapping units in the entire wetland complex.



a.



b.

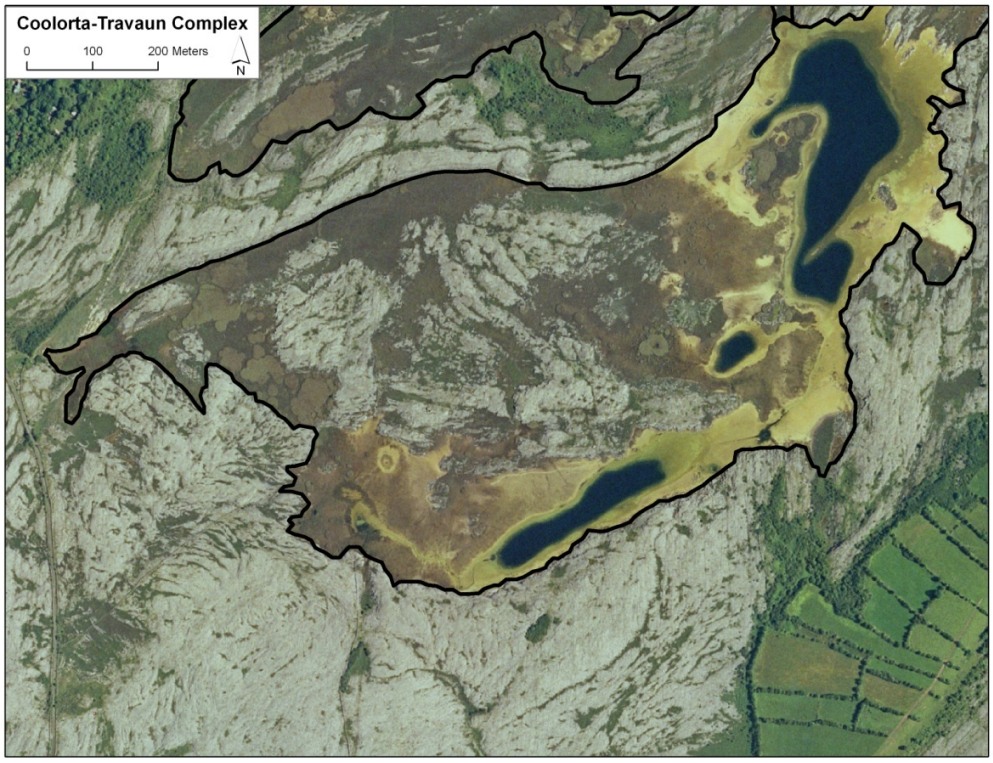
Figure 42 a.) Skaghard Lough wetland subcomplex, b) distribution of mapping units in the Skaghard Lough subcomplex.

Coolorta-Travaun-Aughrim Wetland Subcomplex

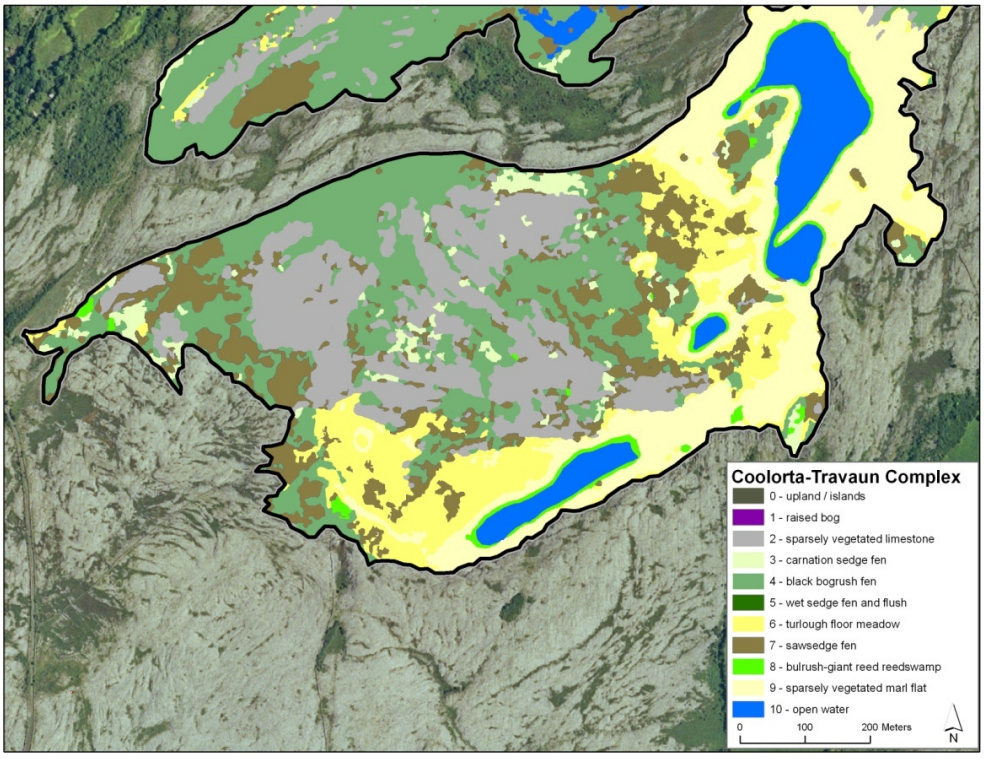
Coolorta-Travaun-Aughrim Wetland Complex contains the receiving basins of the Skaghard-Coolorta-Travaun-Aughrim wetland complex and composes the most extensive turlough complex in the park. The western edges of the complex are dominated by fen vegetation with extensive exposed limestone. The central basins around Coolorta and Travaun have extensive marl flats and fairly sterile lake basins. More extensive areas of the turlough floor support a very sparse cover of shoreweed and many-stalked spike rush around the edges, with the central areas largely bare marl. Lough Aughrim is somewhat isolated from the rest of the complex by a low limestone ridge, and comprises a pond basin in the midst of the northeast arm of the complex. This area is intermediate between fen and turlough in character and characterized by low stature, but fairly continuous graminoid vegetation. Exposed limestone is the most common type within the complex, though most of the limestone appears to be above the level of frequent flooding. Sparsely Vegetated Marl Flat covers the next largest share of the area (19.5%), followed by Black Bogrush Fen (19.2%), and Turlough Floor Meadow (17.8%), and Sawsedge Fen (11.0%; Table 4). During field sampling, we observed that much of the higher area around the edge of the wetland complex was closely cropped, apparently by grazing horses and cattle, which we observed frequently. Although feral goats were nearby, we did not see them in this or any other of the wetland basins.

Table 4. Wetland composition the Coolorta-Travaun-Aughrim subcomplex of the Skaghard-Coolorta-Trauvaun-Aughrim wetland complex.

Map Unit	Type Name	Hectares	Percent of Wetland area
4	Black Bogrush Fen	14.51	19.22
8	Bulrush-Common Reed Reedswamp	1.46	1.93
3	Carnation Sedge Fen	1.80	2.39
2	Limestone	16.43	21.76
10	Open Water	4.85	6.42
7	Sawsedge Fen	8.29	10.99
9	Sparsely Vegetated Marl Flat	14.74	19.53
6	Turlough Floor Meadow	13.40	17.75
	Total Area (ha)	75.47	100.0

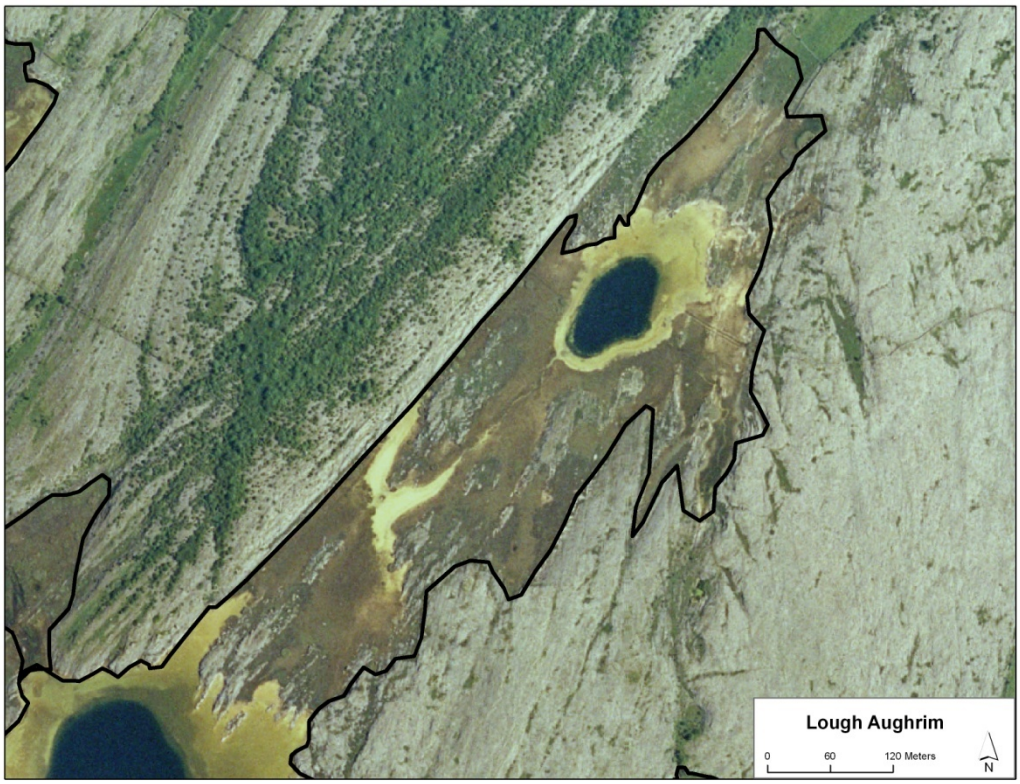


a.

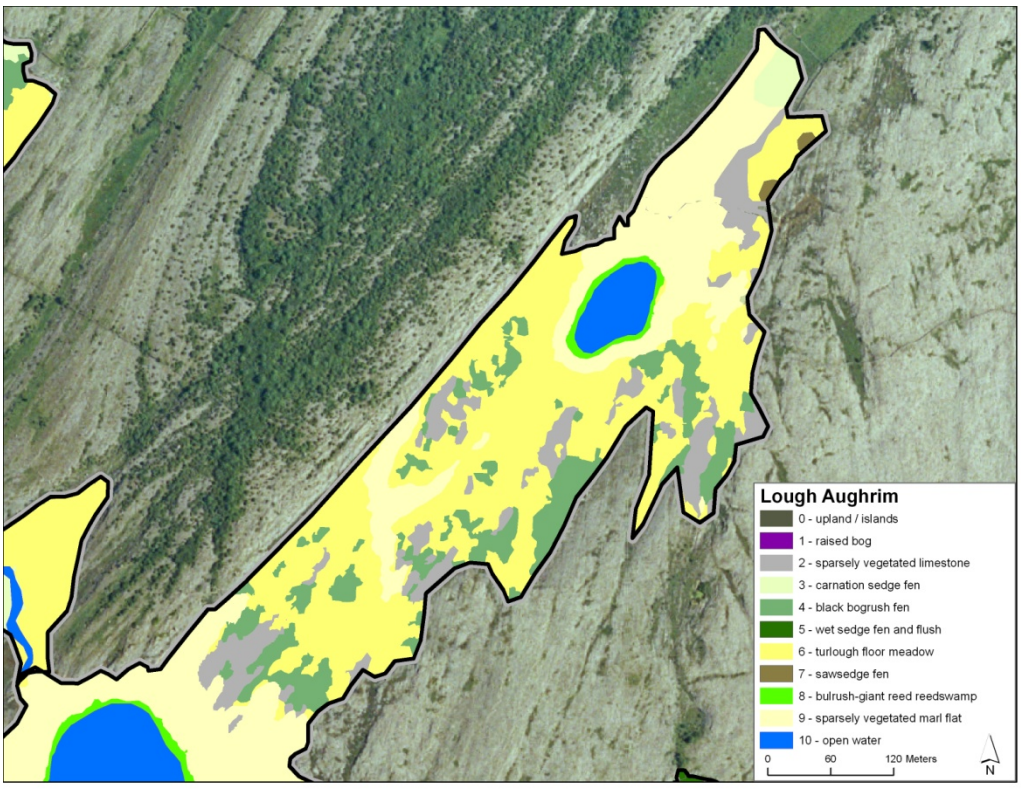


b.

Figure 43 a.) Coolorta-Travaun Area of Skaghard-Coolorta-Travaun-Aughrim Wetland complex, b) distribution of mapping units in the Coolorta-Travaun area.



a.



b.

Figure 44 a.) Lough Aughrim area of Skaghard-Coolorta-Travaun-Aughrim Wetland complex, b) distribution of mapping units in the Lough Aughrim area.

Lough Awaddy and Aughrim Ponds

Lough Awaddy and Aughrim Ponds are relatively small but strikingly distinct scenic wetlands hidden in the limestone pavement between Lough Travaun and Lough Bunny. Each contains a deepwater area connected with the karstic groundwater source, and a combination of semipermanently temporarily flooded fen and turlough types. Lough Awaddy has two notable dolines fringed by a rich array of bulrushes, common reed, sawsedge, and wet sedge fen vegetation. The deepwater habitat is also well vegetated with submergent aquatic vegetation, but that was not sampled in this survey. Aughrim Ponds appear to have small deepwater connections, but are generally shallow over much of their surfaces with more sawsedge and turlough vegetation. Overall, the wetland basins have water above the ground surface much of the year, with Sawsedge Fen (31.1%), and Bulrush-Common Reed Reedswamp (18.9%), the most common wetland community types present (Table 5). Much of the remainder is seasonally flooded Sparsely Vegetated Marl Flat and Turlough Floor Meadow community types. Excellent stands of tufted sedge form the Turlough Floor Meadow Type in Aughrim Ponds, suggesting relatively recent and incomplete colonization of exposed marl surface. Much of the surface of each of the wetland basins is inundated for considerable periods of the year, and livestock grazing appears to be limited to the upper margins, in primarily the Carnation Sedge Type.

Table 5. Wetland composition of Lough Awaddy and Aughrim Ponds complexes.

Map Unit	Type Name	Hectares	Percent of Wetland area
8	Bulrush-Reed Reedswamp	0.67	18.88
3	Carnation Sedge Fen	0.29	8.23
2	Limestone	0.44	12.41
10	Open Water	0.04	1.25
7	Sawsedge Fen	1.10	31.12
9	Sparsely Vegetated Marl Flat	0.47	13.40
6	Turlough Floor Meadow	0.43	12.30
5	Wet Sedge Fen And Flush	0.09	2.42
	Total Area (ha)	3.5	100.0

a.



b.



Figure 45. Lough Awaddy: a) Lough Awaddy ponds. Note zonation from aquatic to wet sedge to common reed vegetation, b) View into largest pond illustrating floating and submergent aquatic vegetation.

a.



b.



Figure 46. Aughrim Ponds. a) View across western pond showing rimming limestone, small pond and turlough vegetation. b) View north across eastern pond showing Turlough Floor Meadow with tufted sedge in foreground and Sawsedge Fen type in background.

a.



b.

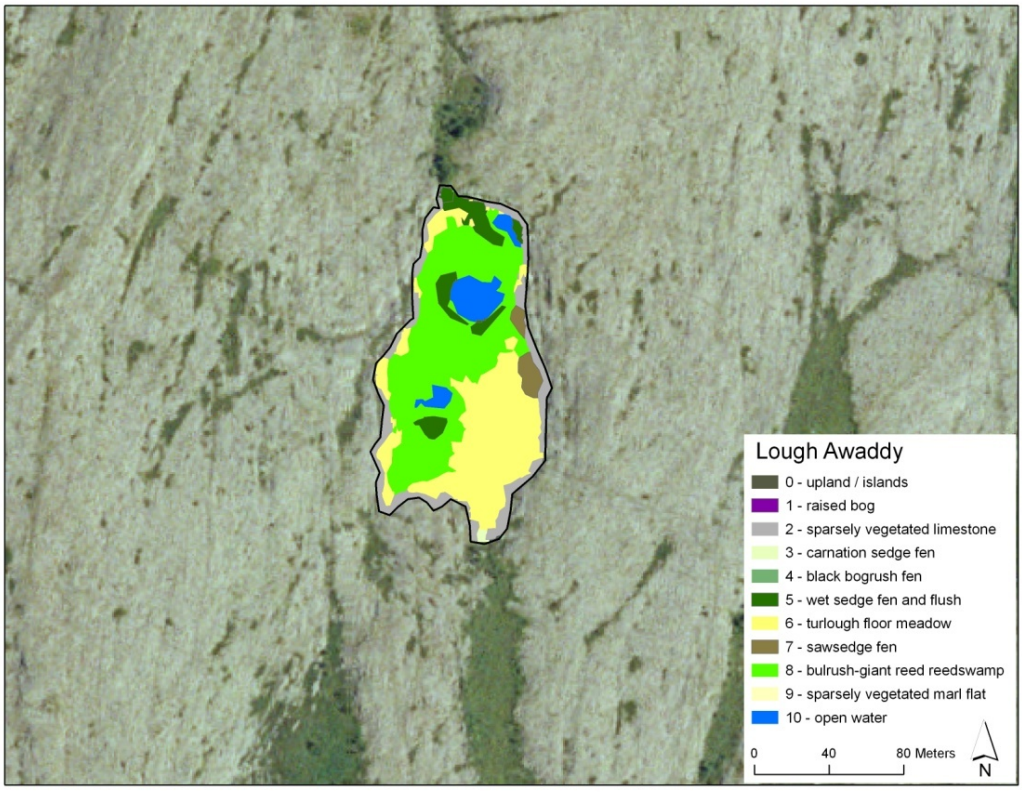
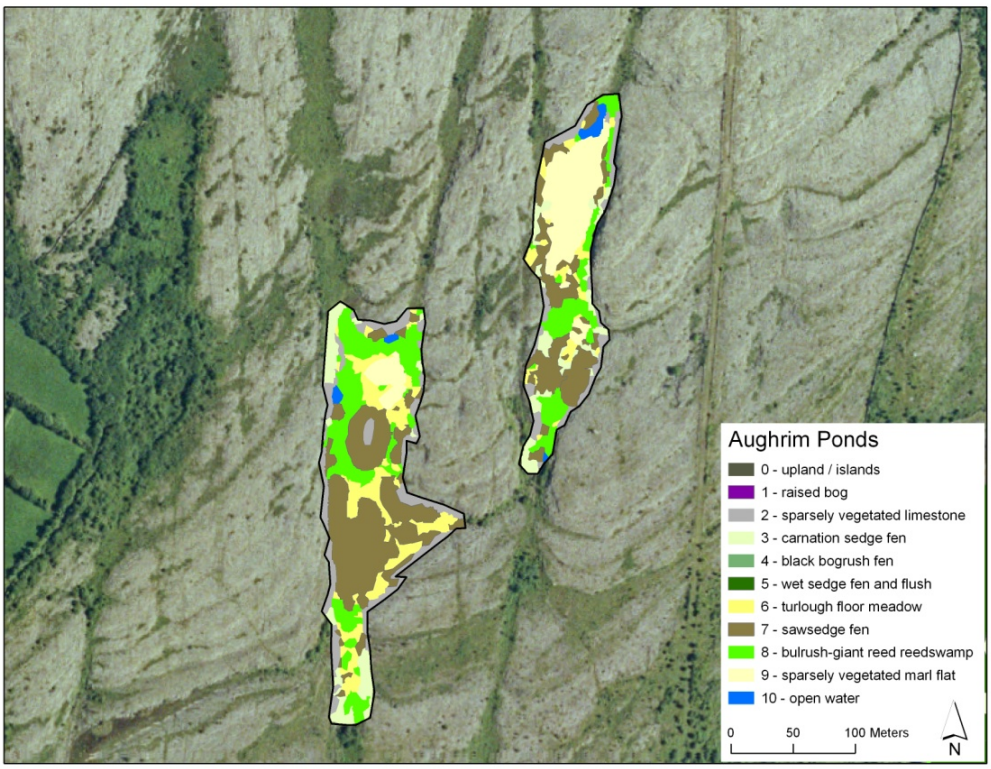


Figure 47. Lough Awaddy: a) overview of Lough Awaddy, b) distribution of mapping units in wetland.



a.



b.

Figure 48. Aughrim Ponds: a) overview of Aughrim Ponds, b) distribution of mapping units in Aughrim Ponds.

Coolreash Fen

Coolreash Fen, a two parted wetland depression within the limestone that straddles the park boundary, is deeply inundated in winter, but in summer forms a scenic fen complex that is heavily used by livestock. Most of the wetland is Carnation Sedge Fen (46.9%) and Wet Sedge Fen and Flush (24.6%), but with a substantial amount of Turlough Floor Meadow and Sawsedge Fen in the deeper parts of the basins. The northernmost basin of the wetland complex shows a complex concentric pattern of wetland from the deepwater habitats in the lowest elevation through Sawsedge, Black Bogrush, and Carnation Sedge Types at increasing relative elevations. Much of the Carnation Sedge Type appears to be closely cropped by livestock. At the time of field sampling, the southern half of the northern wetland was closely cropped, whereas the northern half was relatively ungrazed.

The southern basin appears to be a combination of Carnation Sedge Fen, Wet Sedge Fen, and very limited Sawsedge Fen, with much less deepwater habitat. It appears to be heavily used by livestock and closely cropped. However, we did not conduct any field sampling in the southern basin, so such inferences are made from photo interpretation, and are speculative.

Table 6. Wetland composition of the Coolreash Fen complex.

Map Unit	Type Name	Hectares	Percent of Wetland area
4	Black Bogrush Fen	0.53	4.56
8	Bulrush-Reed Reedswamp	0.04	0.38
3	Carnation Sedge Fen	5.49	46.92
10	Open Water	0.15	1.25
7	Sawsedge Fen	0.89	7.62
6	Turlough Floor Meadow	1.72	14.70
5	Wet Sedge Fen And Flush	2.87	24.56
	Total Area (ha)	11.7	100.0

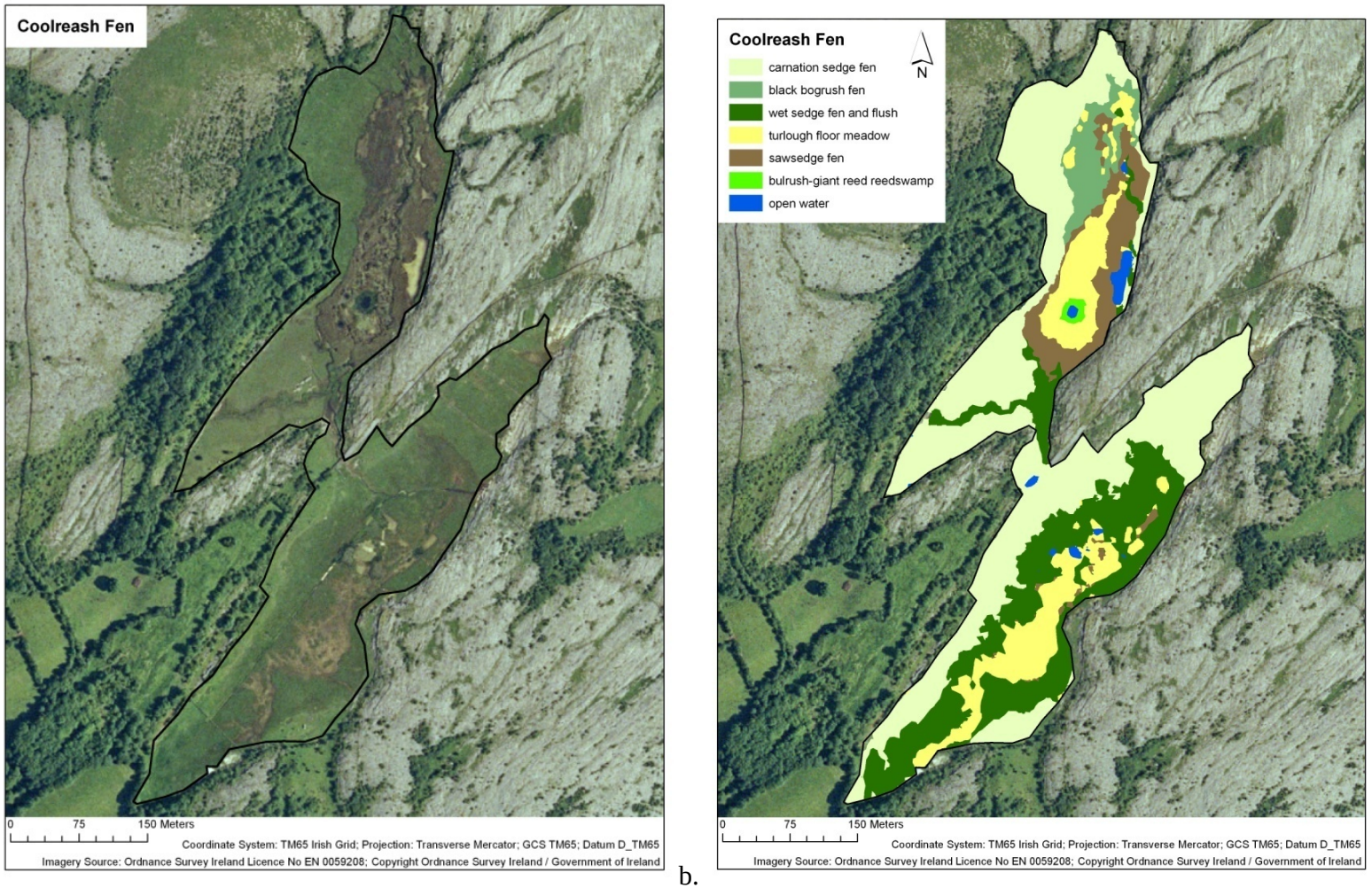
a.



b.



Figure 49. Oblique view of Coolreash Wetland Complex: a) looking south from near center of wetland complex, b) looking northwest from east edge of wetland complex.



a. b.

Figure 50. a.) overview of Coolreash Wetland Complex, b) distribution of mapping units in the Coolreash Wetland complex.

Lough Gealáin Wetland Complex

Lough Gealáin or *Gortleck,* along with Mullagh Mor, is the central scenic feature of BNP. This beautiful wetland is spatially and vegetatively complex, with an array of fen features around the periphery, and more extensive turlough and deep lake features in the larger central basin. Much of the wetland and lake basin is shallow and prone to wide fluctuations (Figure 51), yet the central doline area exceeds 13 m in depth (Byrne and Reynolds 1982), suggesting a substantial bedrock hollow of dissolution or modified glacial origin. Within the central basin, vegetation changes from Flooded Limestone Types with substantial populations of shrubby cinquefoil to Black Bogrush Fen, and extensive areas of Turlough Floor Meadow, and conspicuous but discontinuous stands of Sawsedge Fen (Figure 51b). The fen areas, which occupy somewhat elevated areas around the central basin are dominated by Black Bogrush Fen, Wet Sedge Fen, and Sawsedge Fen. Lough Gealáin Fen, a disjunct fen just east and slightly upslope of the main wetland complex is an interesting example of a wetland basin which has nearly filled with peat and associated fen vegetation, but nonetheless has a remaining nearly circular central basin of deeper water. It contains a notable "mushroom rock" at the eastern edge, suggesting stable water levels of just over 1m above the present wetland surface at some time in the past. A distinctively wet and stable fen at the northern arm of the Lough Gealáin basin contains a nearly pure stand of the Wet Sedge Fen and flush type, with a vivid green color in and a rich mixture of sedges, horsetails, and other semiaquatic plants, such as marsh marigold (Figure 52c). It should be noted that vegetation sampling was limited to only three transects, all on the east and northern edges of the wetland. This wetland could easily be sampled at three times the sampling effort we were able to complete in our short visit.

Table 7. Wetland composition of the Lough Gealáin wetland complex.

Map Unit	Type Name	Hectares	Percent of Wetland area
4	Black Bogrush Fen	4.99	20.85
8	Bulrush-Reed Reedswamp	0.66	2.78
2	Limestone	2.22	9.28
10	Open Water	2.36	9.86
7	Sawsedge Fen	1.46	6.09
9	Sparsely Vegetated Marl Flat	6.07	25.40
6	Turlough Floor Meadow	5.62	23.51
5	Wet Sedge Fen And Flush	0.53	2.22
	total area (ha)	23.91	

a.



b.



Figure 51. Water levels in Lough Gealáin in spring 2008: a) April 24th, b) June 19th. Much of Lough is less than 2m in depth.

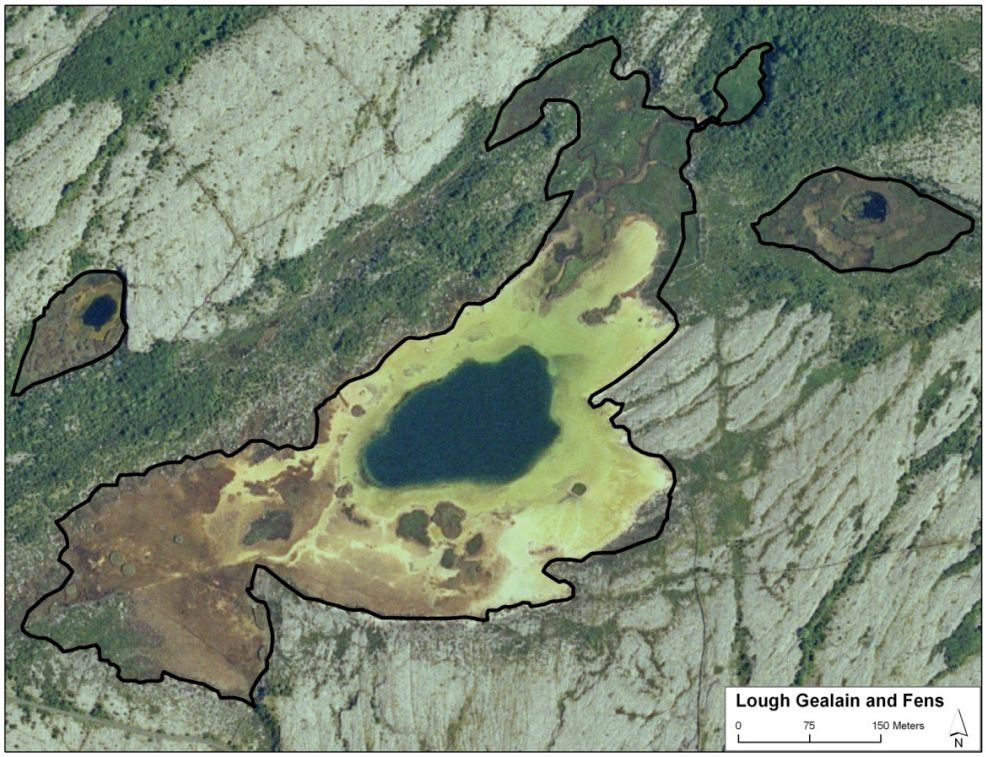
a.  b. 

c.



Figure 52. Fens in the Lough Gealáin Wetland Complex: a) oblique view of Lough Gealáin Fen, b) mushroom rock in Lough Gealáin Fen, c) Wetland Fen and Flush Vegetation in Lough Gealáin Arm.

a.



b.

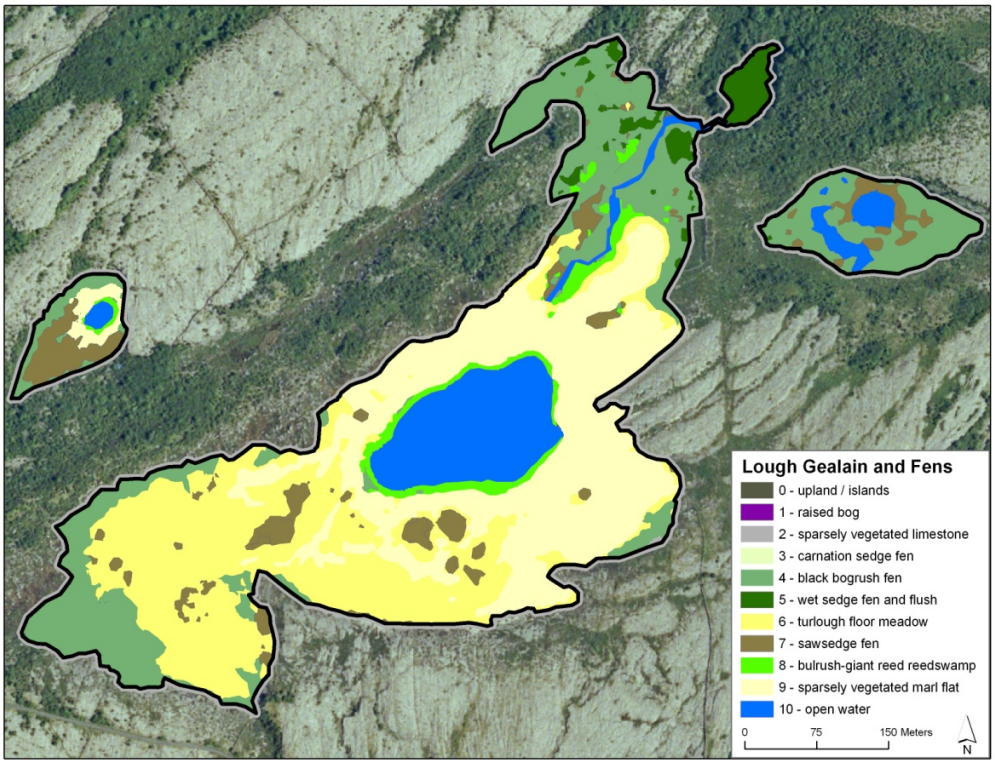


Figure 53. Lough Gealáin Wetland Complex: a) overview of Lough Gealáin wetland complex, b) distribution of mapping units in complex.

Knockanroe Turlough

Knockanroe Turlough, which occurs just south of the main access road into the park, is frequently visited by park visitors and presents the visage of a lake, shallow reedswamp, or moist meadow through the year. It is nowhere deep, but sizable, with a complex mosaic of vegetation and land forms. Several reefs of limestone pavement penetrate the wetland and along their edges the Black Bogrush type dominates, and is the most extensive, though not the most visibly prominent type present. Knockanroe presents the most easily accessed and best developed examples of Turlough Floor Meadow in the park, with sizable stands of tufted sedge, but relatively little area of Sparsely Vegetation Marl Flat. We did not distinguish the Sawsedge Fen type in this wetland, though tufts of the species are scattered across the turlough floor. These patches were typically well below the 10m x 10m (0.01 ha) minimum mapping unit size that we recognized in the mapping effort.

Table 8. Wetland composition of the Lough Gealáin wetland complex.

Map Unit	Type Name	Hectares	Percent of Wetland area
4	black bogrush fen	9.33	33.63
3	carnation sedge fen	3.16	11.40
2	limestone	5.60	20.18
10	open water	0.11	0.40
7	sawsedge fen	0.08	0.29
9	sparsely vegetated marl flat	1.23	4.44
6	turlough floor meadow	8.23	29.66
	total area (ha)	27.75	

a.



b.

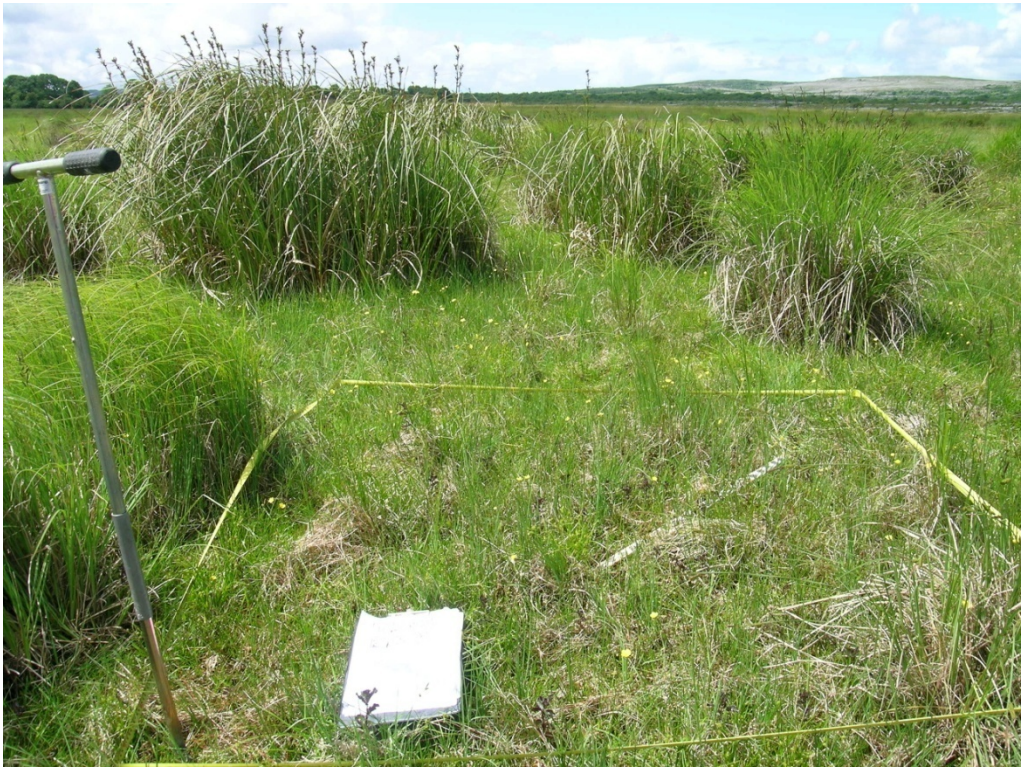
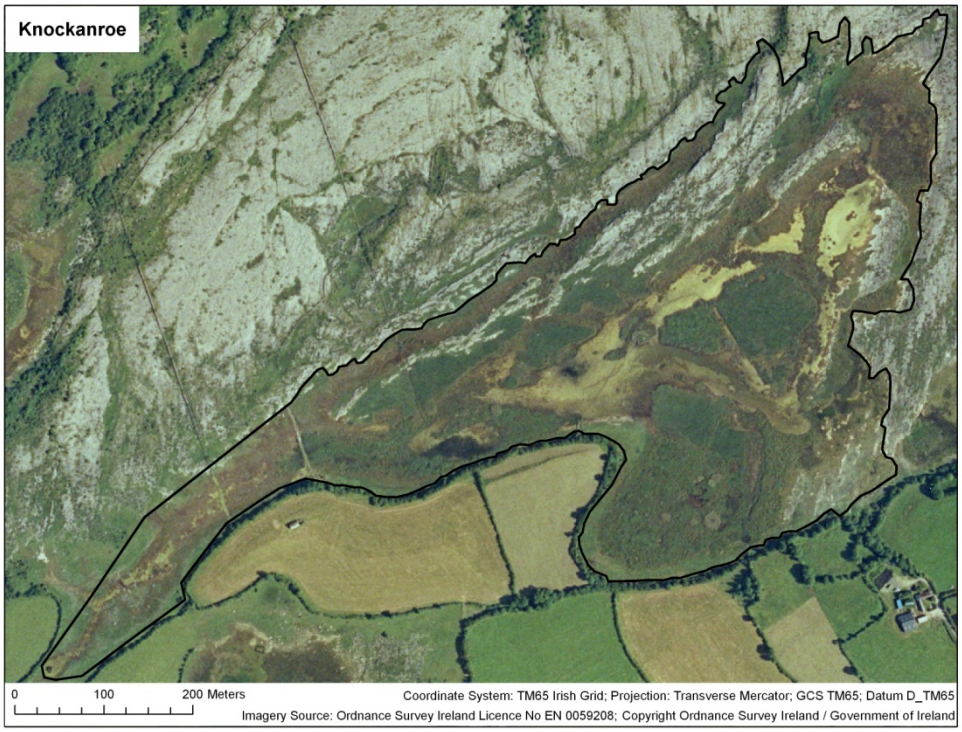
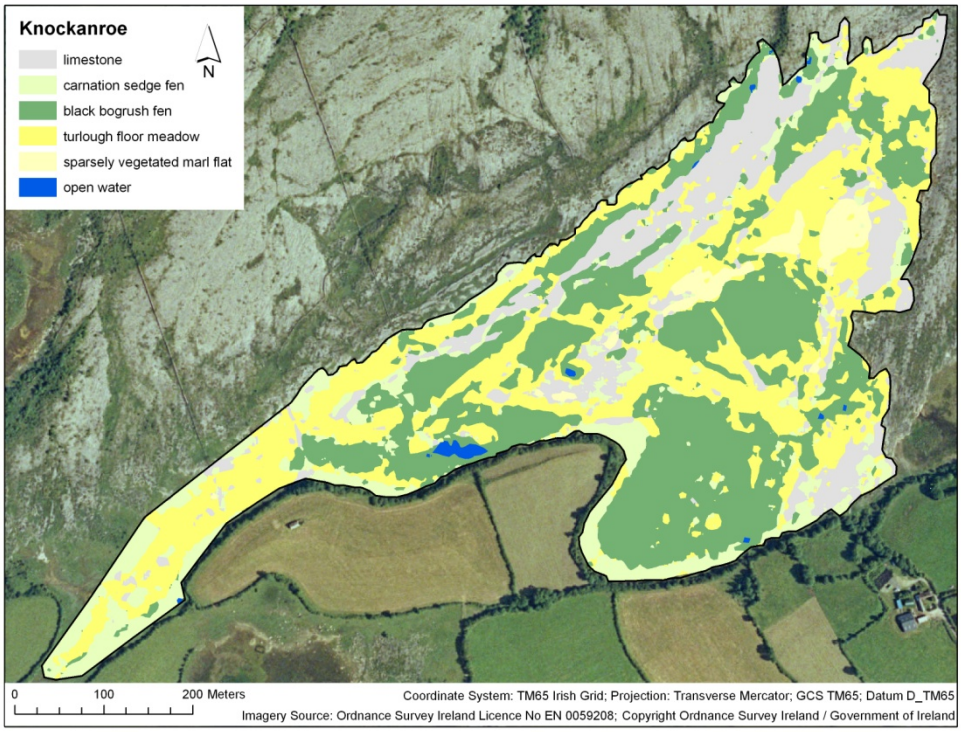


Figure 54. Views of Knockanroe Wetland Complex: a) view north towards Mullagh Mór, b) view of sampling relevé in Knockanroe, illustrating Turlough Floor Community, with patches of sawsedge (*Cladium mariscus*).



a.



b.

Figure 55. Views of Knockanroe Turlough Complex: a) orthophoto view, b) distribution of mapping units in the wetland.

Patterns of Floristic Diversity

Across all the wetland sites, vascular plant species richness ranges from 2-31 species / 4 m^2 relevé with a decrease in the mean and variance in richness associated with increasing biomass (Figure 56a). The highest biomass communities (typically Sawsedge Fens) were poor in species, yet low biomass communities showed very high and low species richness. This was caused in large part by the variety of low biomass communities. Carnation Sedge Fens and both limestone communities were very rich in species, whereas Sparse Marl Flat communities were poor. Most of the intermediate biomass communities (sedge fens) were moderately rich in species. Another fairly obvious pattern was that higher, less frequently flooded areas had higher species richness than sites deeper in the wetland (Figure 56b). This was due in part to flooding, but also the upper edges of the wetland were more heavily grazed and showed lower biomass than middle and lower wetland zones.

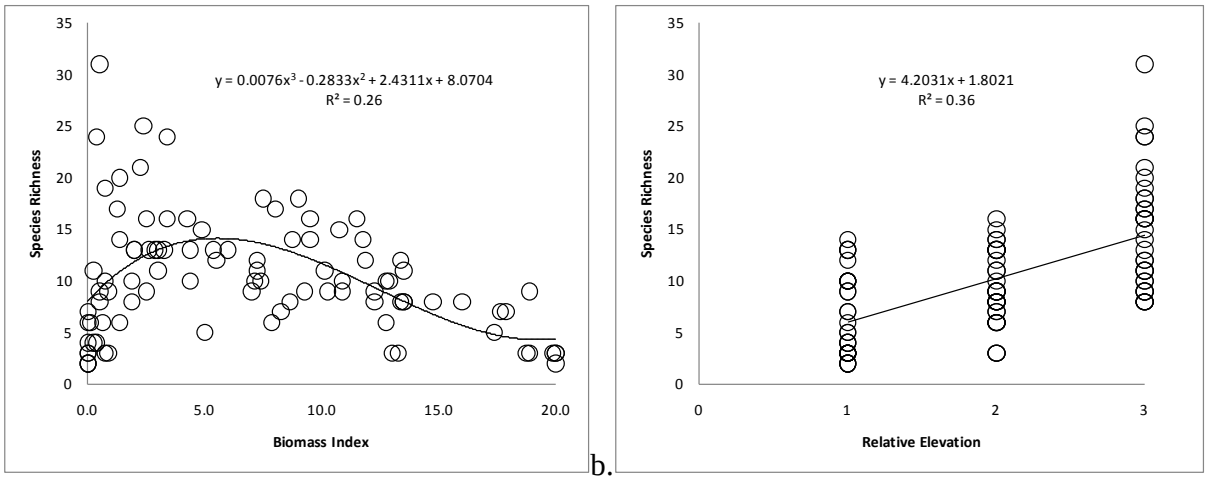


Figure 56. Species richness univariate scatterplots (species / 4m^2 relevé). a) Relationship between species richness and biomass index, b) relationship between relative elevation and species richness.

Multiple regression analyses yielded a six variable model that explained approximately 63% of the variance relevé species richness (Table 9). The stepwise function consistently selected relative elevation and biomass index as key predictors of species richness, with a positive and negative regression coefficients, respectively. Four additional variables were included in the final regression model. Litter, as well as biomass, with which it was associated (r= 0.60), had a negative coefficient. Bare ground and soil pH had negative coefficients, whereas exposed limestone rock had a positive coefficient.

Table 9. Coefficients of determination and statistical significance of component factors in best model selected by stepwise multiple regression analysis.

MODEL R^2	**ADJUSTED R^2**	**F-RATIO**	**P-VALUE**
0.66	**0.63**	**28.29**	**0.000**

VARIABLE	COEFFICIENT	T-STATISTIC	P-VALUE
CONSTANT	31.435	6.189	0.000
RELEV	2.218	4.178	0.000
BARE	-0.115	-6.077	0.000
BMINDEX	-0.409	-4.917	0.000
LITTER	-0.113	-3.465	0.001
ROCK	0.096	3.584	0.001
PHAV	-2.693	-4.235	0.000

A regression tree of the same data supported similar, though less complex relationships (Figure 57). Areas at high relative elevations had generally high species richness, with the richest sites occurring at relevés with low biomass index. At lower relative elevations (left trunk of regression tree) areas with high amounts of bare ground (marl flats) had the lowest species richness. Areas with less bare ground (vegetated communities) were best distinguished by biomass. Areas with high biomass (BMI > 13.0; typically Sawsedge Fen) were notably poor in species.

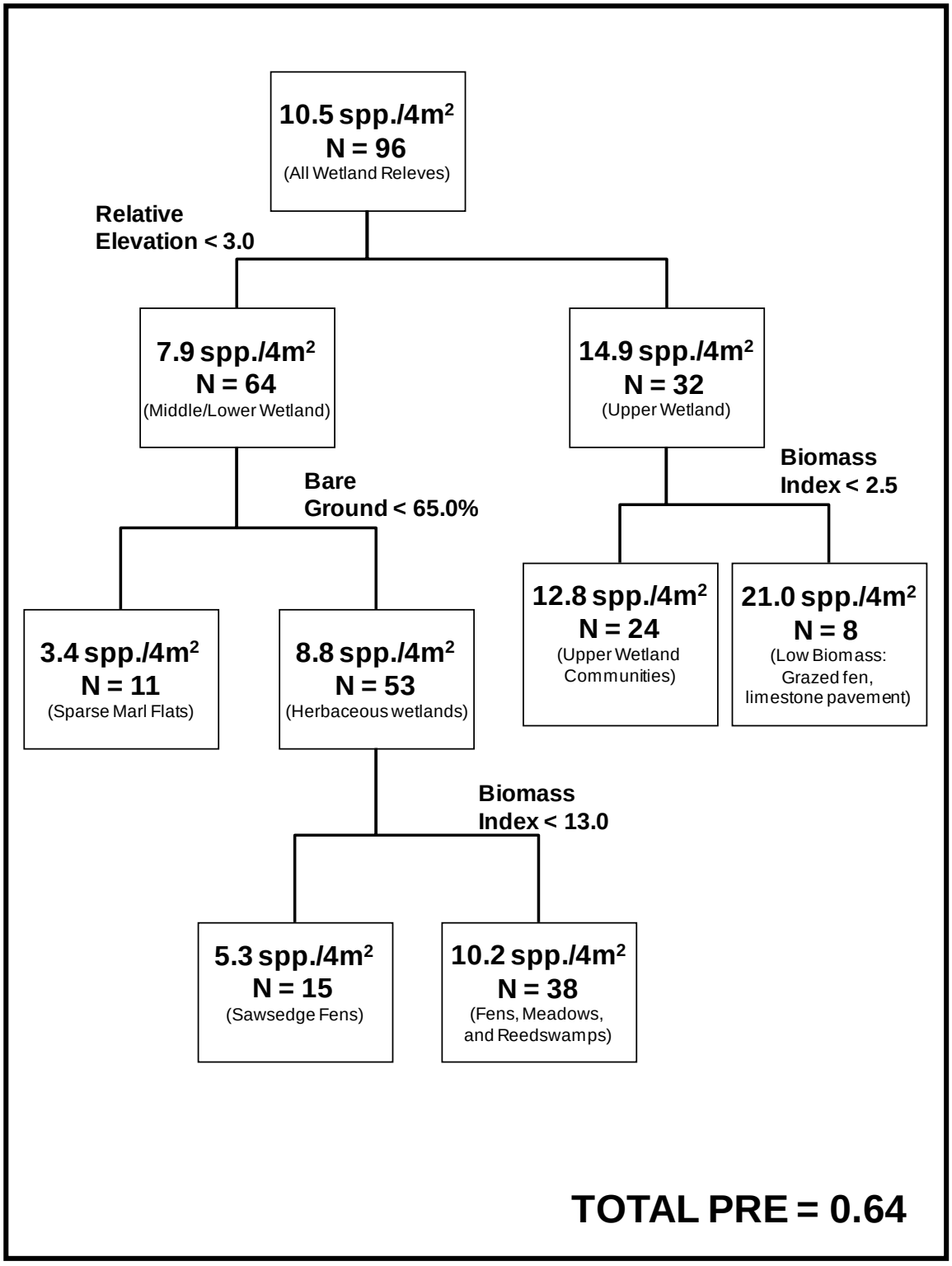
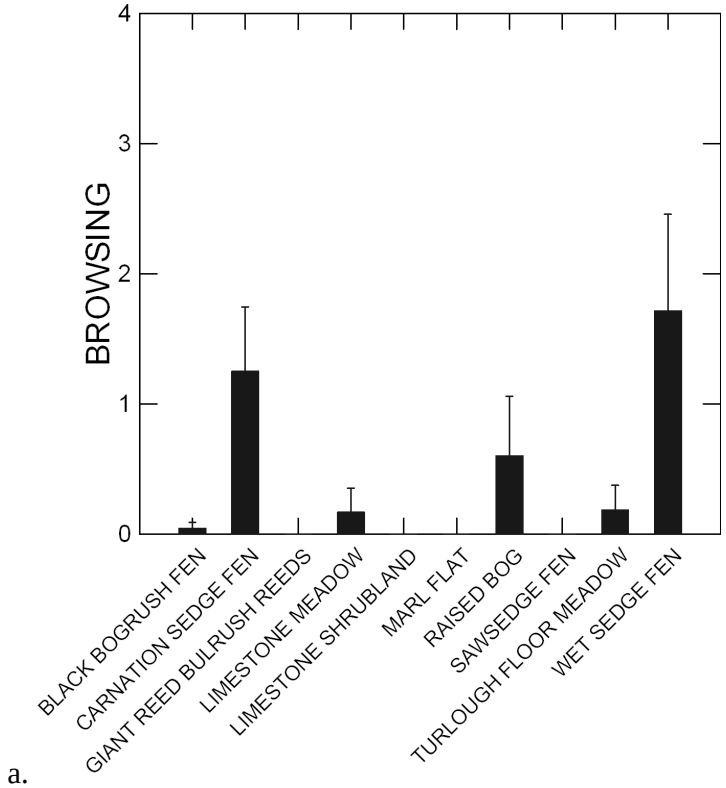


Figure 57. Regression tree illustrating conditions of high and low vascular plant species richness in Burren National Park wetlands. Total PRE=Total Proportionate Reduction in Error (analogous to coefficient of determination in regression models).

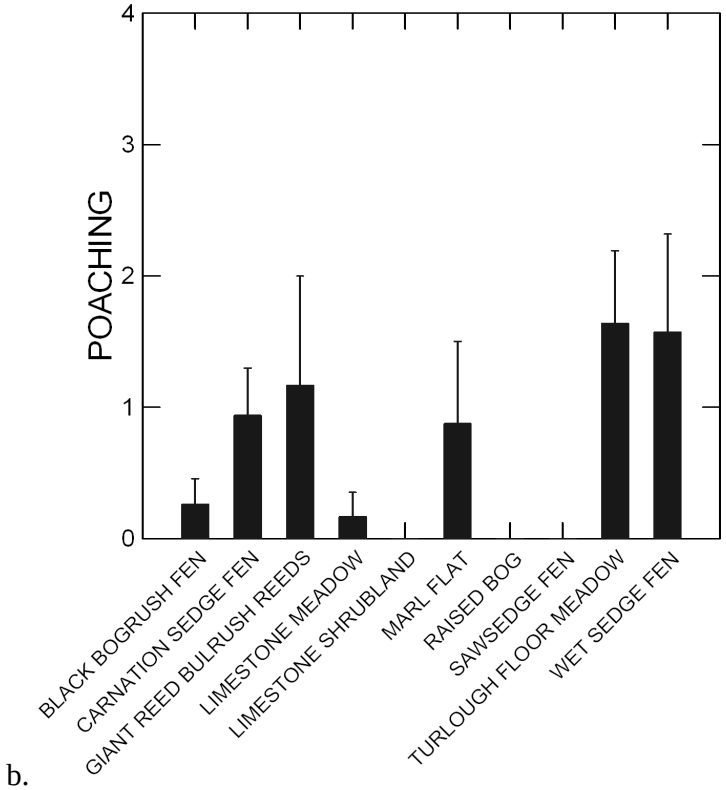
Patterns of Livestock Use and Impact

During the field inventory we observed sporadic livestock grazing by domestic livestock, primarily cattle and horses in both the Ballyeighter and Skaghard-Coolorta-Travaun wetland complexes. Although a herd of feral goats was frequently seen on the rough limestone slopes of Mullagh Mor, we never saw them in the wetland complexes. Livestock browsing differed significantly across the community types sampled (ANOVA, $F_{9,86}$= 3.69, P = 0.001); it was most notable in the Carnation Sedge and Wet Sedge Fen Community types, which were often cropped to less than 5 cm in height at the time of sampling (Figure 58a). We noted little or no browsing in Black Bogrush, Sawsedge Fen, and Bulrush-Common Reed Reedswamp types. Bulrush-Commont Reed and Sawsedge types were often inundated or on fractured bedrock, respectively, so livestock access may have been somewhat limiting. Black Bogrush, as the most common wetland type in the park, and often occurring upper reaches of the wetlands, seemed to be notably underutilized, perhaps due to poor palatability. Certainly, sawsedge and common reed appeared to be largely unpalatable and unused. The low levels of utilization on Limestone Shrubland were not easily explained, given the feral goats and livestock in the area. Poaching was more widely recorded, but still differed notably across community types (ANOVA, $F_{9,86}$= 2.34, P = 0.02); the highest levels were in the community types that were wettest at the time of sampling (Figure 58b), with again the Sawsedge Community type excepted.

Generally, the visible impacts of livestock varied across the elevation gradient (Figure 59). Whereas browsing was most visible in the upper elevations, poaching appeared to be most evident in lower, wetter parts of the wetland complexes. Neither difference was significant in this survey (ANOVA, $F_{2,93}$: < 1.0, P > 0.25), due to high variation in both indices. We observed livestock grazing chiefly at the edges of the wetland complexes in the fen types, but evidence of poaching was present in many of the lower complexes, particularly near sinkholes, where sod cover was thin and wet soils were easily deformed.



a.



b.

Figure 58. Mean (+ s.e.) levels of livestock impact in each of the major wetland community types of BNP: a) browsing, and b) poaching.

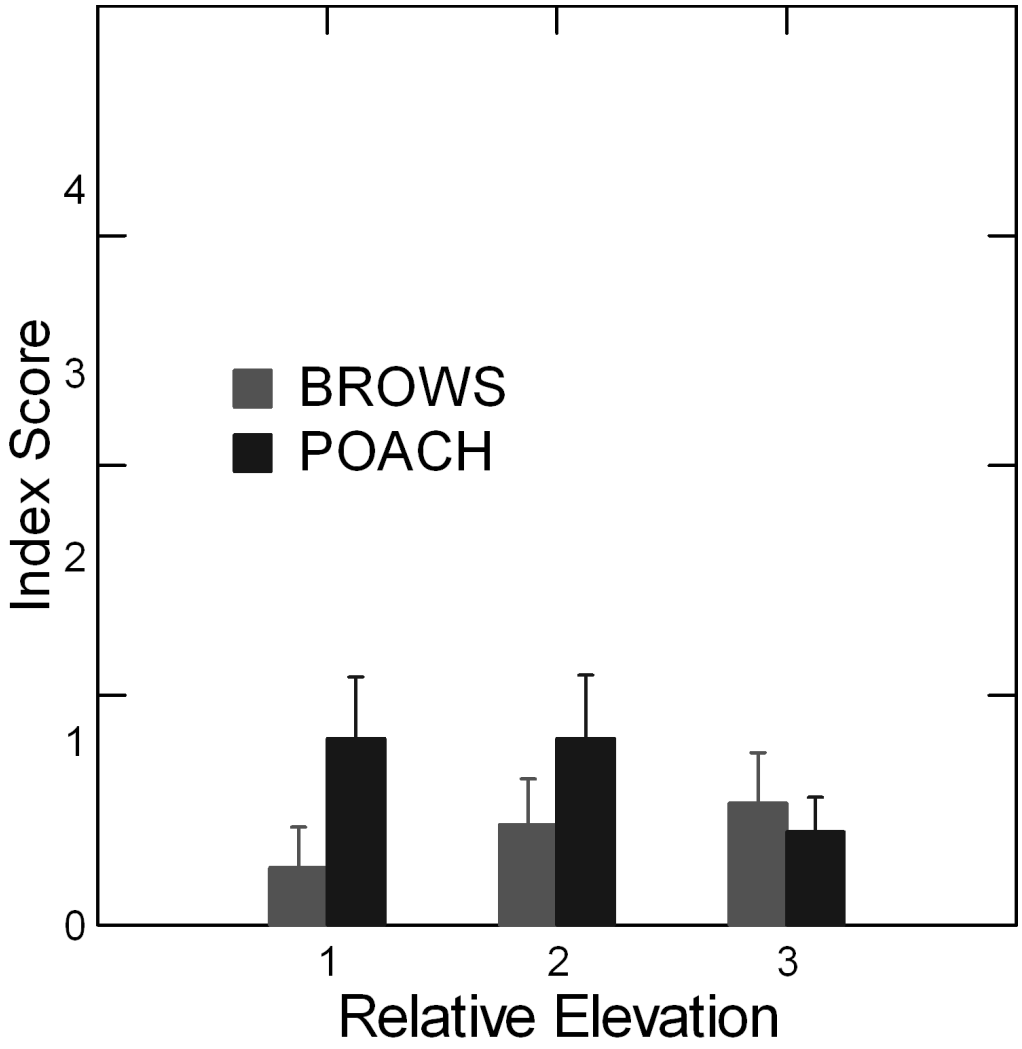


Figure 59. Mean (+ s.e.) browsing and poaching index score in the three relative elevations sampled (n= 32 per elevation) class.

Discussion

Study Limitations

This study was based on one month of fieldwork in one year. Clearly such an effort should be considered preliminary, and does not provide detailed data on all the park's wetlands. In particular, greater effort in the Lough Gealáin area and the far west of the park is warranted. The field data set of 96 relevés does a good job of describing the dominant (e.g., Black Bogrush, Carnation Sedge Fen) or characteristic (Sawsedge Fen) types, but some of the others could

undoubtedly benefit from additional study. Also the color orthophoto provided by the Irish Ordnance Survey was not sufficiently detailed to differentiate fine scale vegetation patterns in these wetlands. Perhaps most importantly, no ground-truthing was conducted to evaluate the map class attributions. Although we estimate that the minimum mapping unit for most of the relatively distinct types (e.g., Sawsedge Fen, Marl Flat) could be as small as 0.01 ha, for other less clearly distinguished types (Carnation Sedge Fen, Wet Sedge Fen and Flush), such fine scale discriminations are unlikely. Therefore, this should be considered a descriptive survey, with value for helping to recognize and interpret the wetland types, but would not be sufficiently accurate to provide a quantitative benchmark for evaluating future changes in the park wetlands.

Interpreting the Wetland Landscape of Burren National Park

Burren National Park presents a number of distinctive and clearly recognizable community types, yet it can be viewed more holistically as a dynamic mosaic of hydrologic, ecological, and human interactions over time. Within the BNP, Mullagh Mor forms both the visual centerpiece and the driving hydrogeomorphic feature, where orographic precipitation peaks, rains, and occasional snows percolate downward to recharge the underlying karst aquifers. Ground and surface water flow from the mountain through the park into the River Fergus system draining into the Shannon Estuary. Along these varied and largely occult paths, porous limestone bedrock and lacustrine deposits with different degrees of free drainage allow considerable complexity in wetland hydrology. At highest elevations on the mountain slopes, fens predominate, due to consistent groundwater discharge. These would be *slope* wetlands in Brinson's (1993) hydrogeomorphic classification. These fens yield steady flow into the larger turlough basins downslope, with corresponding increases in hydrologic variability. Examples include the Lough Gealáin Fen, which empties into the larger, more complex Lough Gealáin, which in turn feeds Knockanroe Lough and Ballyeighter Peatland before leaving the park. Due to the porous limestone, much of the connection is below ground during drier periods in summer. Proctor (2010) suggests that areas at the easternmost part of the park, which empty into Lough Bunny, eventually reach Galway Bay through subterranean paths.

Within the individual wetland complexes of BNP, the gradient in elevational and flood duration from edge to center was associated with relatively predictable changes in plant community type. However, there appears to be considerable overlap in many of the widespread types in the park, suggesting that perhaps establishment effects or other contingent factors also play a role in distribution of the major types. For instance, we recorded very little difference in elevation, soil, or

hydrologic variables between the Carnation Sedge Fen and Black Bogrush Fen types in this study. Turfcutting has created a unique gradient structure in Ballyeighter peatland, with remnant raised bog surfaces showing sphagnum, lower pH, and associated calcifuge vascular plant species (e.g., *Carex pulicaris*, *Drosera* spp.), whereas cutover areas which are reconnected to the calcareous groundwater show the typical calcium loving flora of the park.

Proctor (2010) also suggests that the wetlands of the park and environs have been highly dynamic over time, with evidence of peat cutting present in several of the wetland basins and large scale peat erosion evident in Lough Gealáin. Clearly, the evidence suggests that human agency has been a driving factor in these wetlands for a very long time, and patterns of erosion suggest that wind and wave action during winter storms my exacerbate effects of cutting or perhaps overgrazing in some exposed wetlands.

Over longer time scales, the infilling of the limestone basins, and the suitability for wetland vegetation, appears to be driven by both geophysical and biological dynamics. As most of the waters passing through the wetland basins of the park will carry various degrees of dissolved calcium carbonate, physical mechanisms that cause marl precipitation affecting the soil conditions and morphology of the basins. The shallow turloughs at the base of the Skaghard-Travaun-Coolorta-Aughrim complex suggest deposition of marl in the basin floors. Yet the more fen-like basins (Skaghard, Lough Gealáin, Lough Gelain Fen) show a more interesting centripetal pattern of deposition. Byrne and Reynolds (1982) demonstrated that the basin of Lough Gealáin was surprisingly deep (13.5 m), but that marl covered much of the basin floor up to edge of the deep central basin. The deposition of marl around the edges of all three wetlands suggests that biological dynamics, such as photosynthetic uptake of CO_2, may build the flanges of marl upon which further layers of peat can subsequently accumulate. This process seems most intact in Lough Gealáin Fen, which, according to Proctor (2010) has extensive marl under the current peatland vegetation, but still retains a deep central basin. Both Skaghard Lough and Lough Gealáin have extensive marl flats and discontinuous peat islands around their deep central basins, suggesting either incomplete succession, or a more complex history or peat accumulation and erosion. Proctor (2010) suggested the latter scenario for Lough Gealáin, but did not mention of most the other basins. We can do no more than speculate here, but the evidence does seem to suggest a dynamic history with implications for wetland conservation in the park.

Wetland Community Types of Burren National Park

We were able to distinguish ten plant communities in the park based on the 96 relevés we sampled, through cluster analysis and a parallel computer-aided image classification of a park orthophoto. This compares well with the nine floristic groups identified by Regan et al (2007) for 90 relevés in turloughs in SE Co. Galway and NE Clare, but is much lower than the 32 types recognized by Goodwillie (1992) in a larger survey of turloughs. Indicator species analysis suggested that a classification with between 9 and 12 types yielded the best statistical fit for our modest dataset, but it is nearly certain that a more comprehensive sampling effort would have yielded more wetland types, given the complexity in wetland communities in the park. Our primary goal in this effort was to describe the major wetland community types that could be readily identified in the field and

recognized and mapped with remotely-sensed imagery. The community types and mapping units in this report should provide a description of the major types and their relative proportions in the park. Curtin (2009) provided a more detailed floristic treatment from the same data, with the goal of placing them in the proper phytosociological perspective. The reader is referred to that work and other more extensive works (Ivimey-Cook and Proctor 1966) for a more complete floristic treatment.

As noted by Curtin (2009) and Proctor (2010), the broad categories of vegetation in the park are fen, turlough, reedswamp, and lake, arrayed along the gradient of increasing flood duration. Remnant Raised Bog is present in only limited distribution in the Ballyeighter Peatland Complex. The temporarily flooded types occupy the wetland margins and intergrade with the upland vegetation. In particular, the limestone types are not clearly differentiated from the limestone pavement upslope, except for the presence of such characteristic species as shrubby cinquefoil (*Potentilla fruticosa*) and purging buckthorn (*Rhamnus cathartica*) and moss species (*Cinclidotus fontinaloides*) which indicate seasonal inundation. With the exception of the remnant peat surfaces in Ballyeighter, the upper edges of the park wetlands graded directly into limestone pavement. Although the flooded limestone communities were the most species rich of all the habitats sampled, with many shrubs, forbs, and grasses present that did not occur deeper in the wetland basins, we did not see the rich forb communities described in Regan et al. (2007). Shrubs or graminoids dominated nearly all plots, suggesting that the relatively fertile and well drained habitats they described may be less extensive in park wetland than in other locales nearby.

Seasonally flooded fen types occupy much of the wetland basins that are not permanent deepwater habitat. The types are relatively weakly differentiated by the elevational and hydrological variables we measured, but nonetheless showed a noticeable transition from the Black Bogrush and Carnation Sedge fen types, which rarely had water present in June (driest months of the year), to the noticeably wetter Wet Sedge Fen and Flush and Turlough Floor types, where surface water was present through the driest period. With the exception of the Black Bogrush type, these types showed the highest evidence of livestock browsing and poaching. Graminoids strongly dominate each of these fen types as well as the turlough floor meadow, though in the latter bare marl is relatively more common. Organic matter in soil samples averaged between 35-45% for the fen types, dropping to 20% in the Turlough Floor Meadow type. The relative stable hydrology of fens as opposed to turlough types is associated with more favorable conditions for peat formation and higher plant diversity (Proctor 2010).

The semipermanently and permanently flooded types in the park occupy the floors of the lake and turlough basin, often immediately adjacent to the noticeable ponds (Lough Gealáin, Skaghard Lough). The Marl Flat, Bulrush-Reed-Reedswamp, and Sawsedge Fen types all occur in the lowest elevations of the wetland basins, but show important variation in composition, structure, and hydrology. The Sawsedge Fen type often occurred where imestone fractures provided a steady water source, but where surface drying was at least occasionally seen. Most sites were circumneutral or slightly alkaline (pH 6.5-7.5). Sawsedge stands had the highest biomass of all the types sampled, sometimes exceeding 6,000 gm/m^2. The most extensive stands in the park are in the embayments along the southwestern shore of Lough Bunny, were they form nearly impenetrable stands covering

tens of acres. The Bulrush-Reed-Reedswamp type occurred principally as a littoral community around more permanent water bodies, typically occurring where water was most reliable. This was particularly true for bulrush. Exceptions are the sparse stands of reed that occur across the shallowly flooded marl surfaces of Skaghard Lough and Lough Bunny. The Marl Flat communities, which occupy the lowest elevations in the turloughs, occur under conditions so harsh that only a few species survive, and cover is low or absent entirely. The Marl Flat type as we describe and map it includes both the littoral fringe of true sparse vegetation which we sampled, and the more extensive bare marl flats which cover the remainder of the turlough basins.

Biodiversity and Conservation Significance of Burren National Park Wetlands

Wetlands of Burren National Park compose a major share of the East Burren Wetland Complex, which is considered to be one of the finest complexes of oligotrophic, calcareous wetlands in Ireland (NPWS 2001). Sheehy Skeffington et al. (2006) argued that turloughs, in particular, are wetlands of global significance, distinctive to Ireland. Viewed holistically, the wetland landscape of Burren National park is an exceptionally diverse and scenic mosaic of wetland environments.

Within wetlands themselves, floristic species richness is typically described in terms hydrology, environmental heterogeneity, and the interactive influences of disturbance and vegetation response (Wheeler and Giller 1982, Moore and Keddy 1989, Pollock et al. 1998). All these factors appear to be important controls on species richness in the wetlands of Burren National Park. This study yielded several insights about the floristic diversity within and among the wetland plant communities of the park.

First, our data are consistent with other studies that have shows that sustained flooding limits the pool of vascular plant species that can exist on a site. The wetlands appear to have lower diversity than the upland samples of comparable area, as noted in other wetland studies (Ferreira 1997, Casanova and Brock 2000). Moran (2009) recorded 20-34 species / $4m^2$ plot in Burren upland environments, which did not overlap with our estimates for the ten types we described (2.9 – 17.5 species /$4m^2$ for Sparse Marl Flat to Limestone Shrubland, respectively). Indeed, within our wetlands sample, the types lowest in the wetland basins had the lowest richness. The littoral Limestone Shrubland community type was the richest of the communities sampled, and contained the most unique species. The flora of the wetlands shows predictable changes with hydrology, notably the loss of upland or generalist species as one descends into wetland basins, but with an increase in some regionally rare species. For instance, shrubby cinquefoil (*Potentilla fruticosa*) and turlough violet (*Viola persicifolia*) occur within the wetland basins, and enrich the diversity of the landscape overall. At intermediate elevations in the wetland basins, there is considerable overlap in wetlands species from type to type. This may be due to both the opportunistic ways that fen and turlough species disperse and establish in the parks wetland complexes, or perhaps weak hydrologic differentiation in these wetlands. In the hyperhumid climate of the Burren, many wetland species are not so strictly dependent upon permanent flooding as elsewhere, and seasonal flooding and drying of the turloughs in particular, result in interesting juxtapositions of generalist, bog, fen, and reedswamp species.

A second insight is that biomass is strongly associated with vascular plant species richness in wetlands of BNP. As in other studies of species diversity in herbaceous plant communities (Grime

1973), including wetland communities (Moore and Keddy 1989, Wheeler and Shaw 1991, Pollock et al. 1998), species richness in Burren National Park wetlands is highest at relatively low to moderate levels of above ground biomass, and at sites with moderate flood duration. The semipermanently or permanently flooded communities were low in species richness regardless of biomass. Biomass was varied with plant community type and degree of livestock browsing. Sawsedge Fen stands had much higher live and dead biomass than the other types, suggesting high productivity coupled with low decomposition rates and low palatability to livestock. Black Bogrush Fen stands had modest biomass, but also frequently a well-developed litter layer up to 10 cm thick, which inhibited diversity of the ground layer. Carnation Sedge Fen and Wet Sedge Fen and Flush community types had low to moderate biomass, and moderate to high floristic diversity. The richest plots were consistently those with closely cropped vegetation under 15 cm tall and that contained many small forbs. Plots that fell on shallow soils with exposed bedrock were also very rich, potentially due to shallow soils limiting the biomass such that no species dominated the plot.

A third insight is that environmental heterogeneity at several scales enhances diversity in park wetlands. In the Black Bogrush Type, tussocks compensated to a degree for the heavy litter layer by increasing microsite heterogeneity as the elevated tussock surfaces often showed evidence of acidification and drying, with upland species such as tomentil (*Potentilla erecta*) co-occurring in plots with true wetland species such as bogbean (*Menyanthes trifoliata*). Similarly, at sites where shallow or emergent limestone created soil heterogeneity, or where shallow bedrock depressions allowed acidic peat soils to accumulate, plant species richness was high.

Taken together, we see that the wetlands of the park are controlled by a multiscale combination of factors from interplant competition at the smallest scale to landscape heterogeneity at the park and regional scales. The uniquely complex edaphic, hydrologic, and disturbance patterns in the park at once support hydrologically-linked fen, turlough, and lake wetlands, and allow peat development and associated acid-loving bog species to exist in a landscape of naked limestone.

Clearly, floristic diversity is only one of many dimensions of biodiversity in wetland landscapes, and the shallow lakes and wetlands of the Burren National Park also support a rich array of life (Sheehy Skeffington et al. 2006). A complete review of all taxa is beyond the scope of this report, but bears brief mention to the degree that other species' life histories amplify or contrast with this discussion of floristic diversity. The work of Reynolds (1985, 1996, 2003, and others) sampling aquatic life in turloughs of the park and environs suggests an aquatic fauna well adapted to hydrologic variability. Herbivore and detritivores predominate, with carnivores less common in the nonpermanent waterbodies. Some species of high conservation value can be encountered, including crustaceans, water beetles, and Odonata (reviewed in Sheehy Skeffington et al. 2006). A rich fauna of beetles and butterflies/moths has been recorded from wetlands in the region, with a number being closely associated with wetland vegetation. Generally, vegetation height and complexity have been positively associated with invertebrate diversity in the wetland swards (Bond 1997). Prominent vertebrates include frogs, smooth newts, fish, and water birds. Fish are perhaps most important by their absence or small populations in many of the wetlands. A natural consequence is that invertebrate productivity is available for other species, such as wintering birds.

Threats to Wetland Biodiversity

The primary threats to floristic diversity in Irish turloughs are believed to be livestock grazing and fertilization, either separately or in combination (Ní Bhriain et al. 2004, Kimberley and Waldren 2006). Both represent complex issues because it is known that the Burren has been grazed and manured for many hundreds of years. Although the pastoral systems of rural western Ireland have allowed the persistence many species in the Burren region, recent intensification in both grazing and fertilization poses a potential threat to floristic diversity of the wetlands in the region (Ní Bhriain et al. 2004, Kimberley and Waldren 2006).

Our data are certainly not sufficient to definitively address these complex and interacting concerns. However, the general impacts of livestock, at least at the time sampled, were associated with persistence of wetland floristic diversity. The hyperhumid climate and high productivity of the native wetlands result in a dense sward of largely perennial vegetation that appears superficially resistant to browsing and limited poaching. Closely cropped fen areas showed high floristic species richness at the plot scale in our study. Moreover, the rugged limestone reefs that surround and intrude into many of the wetland complexes create microrefuges for vegetation that would limit accessibility for domestic livestock. At the time of this study (late spring 2008), browsing appeared to be very localized, in a few areas of the park (the north edge of Ballyeighter, west edges of Coolorta, and southern half of Coolreash). These locations appeared to be consistently used, whereas most other areas of the park were much more lightly browsed.

Studies of similar ecosystems have suggested that moderate grazing is often associated with high species richness in rich fen communities. Picking and Veneman (2004) recorded high species richness in a calcareous fen in Massachusetts, USA that they attributed to the influences of grazing on controlling standing crop and enhancing site heterogeneity. Wheeler and Giller (1982), in a study of rich fen vegetation in Britain, noted markedly higher species richness in managed fen stands, which they attributed to control of biomass accumulation and litter development. Studies of rare plant species frequencies in herbaceous wetlands of Canada and Britain have shown strong associations with particularly infertile or grazed wetland types with low aboveground biomass levels (Wheeler 1988, Moore et al. 1989). Therefore, it seems reasonable to conclude that modest grazing is consistent with the maintenance of floristic diversity in park wetlands. However, this conclusion for vascular plant richness should be balanced with the insight that uniformly heavy grazing of wetland vegetation and associated poaching and manuring is likely to negatively affect the diversity of species which use the vegetation as habitat, such as insects (Ni Bhrian et al. 2002, Ryder et al. 2005), or organisms which are sensitive to nutrient addition.

Conclusions and Implications for Management

The wetlands of Burren National Park contain a mosaic of wetland community types associated with gradients in soil moisture and flood duration from edge to center and secondarily with soil chemistry. Proctor (2010) suggested that the wetlands of the park and environs have been highly dynamic over time, with evidence of major geomorphic changes as well as accumulation, erosion, and human extraction of peat resources in several of the wetland basins. The delineation of relatively discrete mapping units in this study, therefore, although a great help in describing the major wetland types,

should be not be interpreted as defining fixed and immutable units. Rather, they may be best viewed as extant clues to the origins, patterns, and dynamics of an ever changing wetland landscape.

Humans have long shaped the Burren landscape. With changes in land use, many of the hydrologic, chemical, and disturbance regimes that characterize Burren wetlands are likely to change. The magnitude and consequences of such changes are unknown. This study suggests, but does not prove, that low intensity land use, such as the moderate levels of livestock grazing and poaching we observed, and which have characterized the traditional low intensity grazing regimes of the Burren, are consistent with the persistence of relatively high floristic diversity in park wetlands. The generality of these findings for vascular plants would be strengthened considerably with comparable study of other wetland-dependent taxa, such as aquatic and terrestrial invertebrates, small mammals, and perhaps ground nesting birds, which could be affected by livestock. There were insufficient observations to determine if current levels of browsing will be sufficient to prevent hazel or other shrub encroachment (Dunford 2002) into the wetland basins, with a possible impact on herbaceous plant species richness. In most cases, the shrubs appear to be limited by seasonal flooding, so such infilling would be limited to the uppermost communities of the wetland basins. Studies of impacts of higher intensity land uses, such as increased fertilization, intensive grazing, or changes in hydrology, would form an important complement to this study, and serve the future conservation of Burren National Park wetlands.

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