Inventory and Mapping of Wetland Plant Communities in Burren National Park, Ireland

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WETLAND LANDSCAPES OF THE BURREN REGION, IRELAND

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, often within complex mosaics created by varied climate, hydrology, and geology (Otte 2003). The Burren (from the Irish 'Boíreann' or rocky place) is a stark, glaciated limestone plateau in the far west of Ireland that is one of the most distinctive and diverse landscapes in northwest Europe. Despite a hyperoceanic climate with over 200 precipitation days a year, extensive limestone and high soil pH limit the dominance of *Sphagnum* and thus the extent of Atlantic blanket bog, which characterizes much of west Ireland (Otte 2003). The scenery and spectacular plant diversity of the limestone pavements in the Burren are world-renowned, yet the wetlands have received less intense interest by scientists and the public than the adjacent uplands. Nonetheless, a rich variety of wetland plant communities have been described in the Burren region, including distinctive marl (calcium carbonate-rich mud), turlough, fen, bog, and reedswamp communities (Praeger 1932, Webb 1964, Ivimey-Cook and Proctor 1966, and O'Connell et al. 1984).

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 (marshes in North America) occur in areas with standing water during the growing season, and are most common around permanent lakes and depressions. As in other cool, hyperhumid regions, western Ireland is especially rich in peatlands. Peatlands (chiefly bogs and fens) tend to have moist to saturated soils through the year, usually with the water table at or below the ground surface. Bogs are peatlands that typically have low pH (generally < 5), low Ca^{2+}, Cl^- and SO_4^- as the dominant anions present, with vegetation dominated by *Sphagnum* mosses, ericaceous shrub species, and calcifuge (calcium fleeing) graminoids (grasslikes plants such as grasses, sedges, and rushes; Proctor 2010). In contrast, fens have higher pH (usually > 6.0), high Ca^{2+} and HCO_3^-, calcicole (calcium loving) graminoids, many herbs and brown mosses. Wheeler and Proctor (2000) emphasized that the distinction between bog and fen is not abrupt, and actual wetlands may have intermediate characters. General classifications of peatland vegetation types have been summarized for Ireland by O'Connell (1984) and Feehan and O'Donovan (1996).

Turloughs are globally unique groundwater-dependent wetlands that occur in limestone depressions in the 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 with the substrate and grazing management being important factors in determining species distribution (Goodwillie 2003).

As with most of the Irish National Parks, Burren National Park (BNP) is a relatively new addition to a long settled landscape (Sarr et al. 2014). The BNP is located

Figure 1. Zonation along shore of Skaghard Lough (Lake), looking southwest toward Mullaghmore Mountain, Burren National Park, Ireland.

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near the eastern edge of the Burren, and contains a series of interconnected wetland complexes that include deep limestone ponds, more extensive, but shallow lakes, fens, bogs, and turloughs. These wetlands form important habitat for native and migratory wildlife, and add greatly to the scenery of the Park (Figure 1).

DESIGNING A WETLANDS INVENTORY

In spring 2008, we met with the scientists and managers of the National Parks and Wildlife Service at Burren National Park to discuss collaborative wetland research needs. 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. 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 1997; Sheehy Skeffington et al. 2006; Regan et al. 2007), site specific knowledge about the status and extent of the wetland plant communities of the Burren National Park was identified as a critical information need. A more comprehensive technical report describes the larger inventory effort and detailed floristic analyses (Sarr et al. in Press). This paper chronicles our effort to conduct a rapid wetland inventory, with limited field work and by leveraging remote sensing and Geographic Information System (GIS) analyses.

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 surrounding area, a set of digital color infrared orthophotos from 2005, from the Irish Ordnance Survey at 1 m resolution, which provided a clear overview of the major wetlands complexes in the Park, as well as impressive detail within each wetland complex (Figure 2). We determined that up to six weeks of field sampling would be available in late spring 2008, allowing collection of no more than about 100 relevé samples. 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.

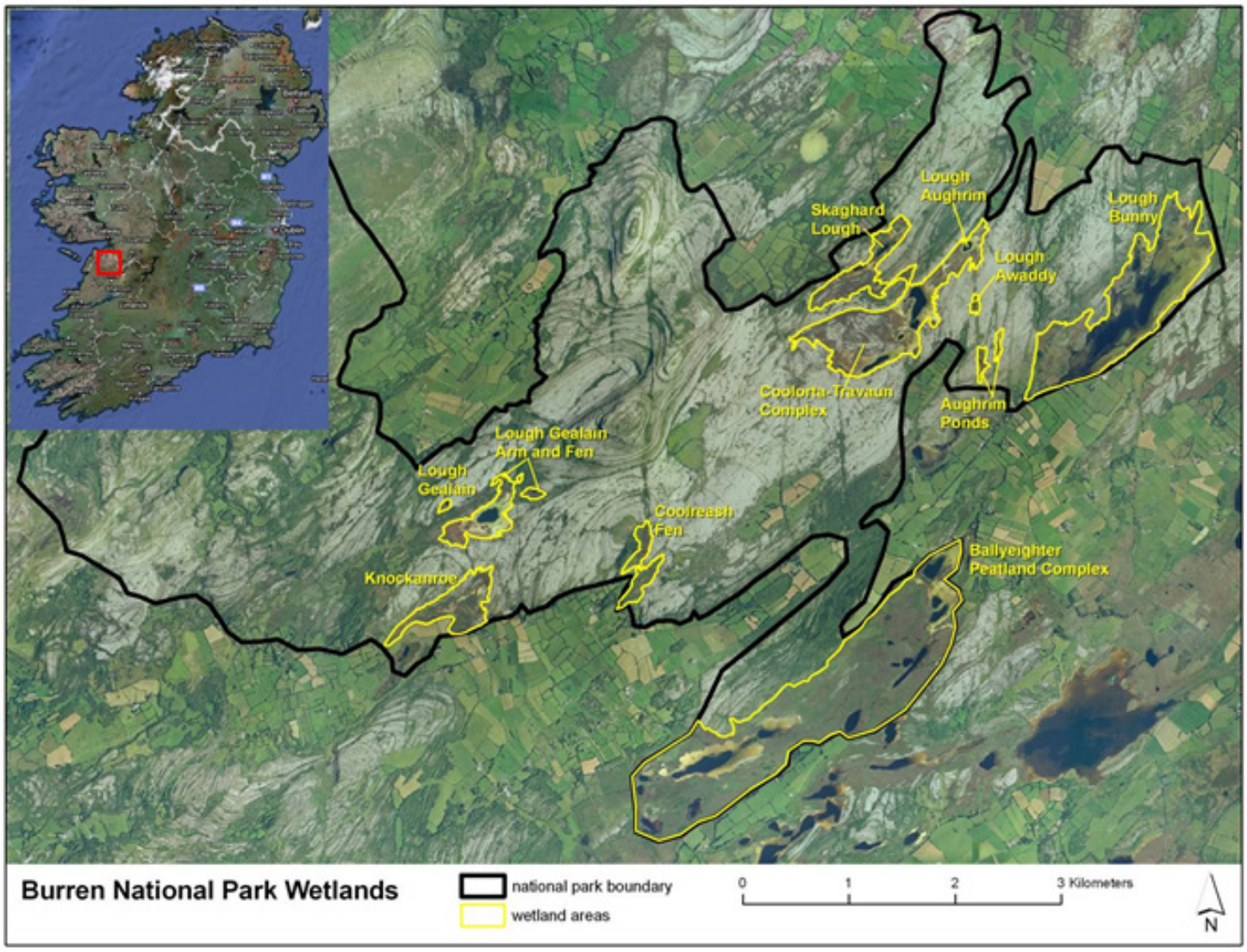

Figure 2. Insert: Location of study area in Republic of Ireland. Burren National Park, with major wetland complexes in the park labeled.

FIELD DATA COLLECTION

Between May 20 and June 25, 2008, vegetation and environmental information were collected in 2 m x 2 m relevés (quadrats), at 96 locations along 32 centripetal transects within wetlands complexes distributed throughout the Park. Each centripetal transect ran from just inside the high water flood mark (as evidenced by flotsam and shoreline moss layers) towards the center of the wetland, and was stratified into three zones, each composing a third of the total length. The relevés were placed a random distance into each zone, creating a balanced sample of high, medium, and low sites along the topographic moisture gradient. Deep water habitats (sites with over 1 m of standing water at the time of sampling) were not sampled. 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.

Geographic coordinates of each relevé were obtained from a Garmin GPSMAP CSx60 global positioning (GPS) unit. Each relevé was attributed with a relative elevation (1-low, 2-medium, 3-high) based on its position on the centripetal transect

IDENTIFICATION OF MAPPING UNITS

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. In this paper we describe the identification and mapping of major wetland types through parallel floristic and image analyses.

Irish Odnance Survey orthophotos 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 and therefore it is important to note that 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).

The floristic and environmental data plus two scales of imagery (photographs taken at each site and the landscape scale orthophoto) were used 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 were therefore aggregated into larger, recognizable mapping units, and that some of the floristic units were placed in the wrong mapping units. Also clearly mappable units were not always floristically homogenous. Nine relevés that were transitional in character were moved from their initial floristic classes and assigned to a broader map class. After inspecting plot maps, five samples were moved to the Turlough Floor Meadow, 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, even though it was floristically heterogeneous.

WETLAND COMMUNITY TYPES OF BURREN NATIONAL PARK

A total of nine mappable vegetation types were recognized from the inventory and classification (Figure 3), along with an obvious open water type. These community types

TABLE 1. HYDROLOGIC AND NUTRIENT STATUS OF MAJOR MAPPING UNITS IN BURREN NATIONAL PARK.

Hydrologic Class	*Nutrient Class*	*Community Type*	*Characteristic Species*
Temporarily Flooded	Ombrotrophic	Raised Bog	*Molinia caerulea, Myrica gale, Erica tetralix, Calluna vulgaris, Sphagnum sp.*
Temporarily Flooded	Minerotrophic	Limestone Shrubland	*Potentilla fruticosa, Rhamnus catharticа, Thymus polytrichus*
Temporarily Flooded	Minerotrophic	Limestone Meadow	*Carex flacca, Agrostis sp.*
Seasonally Flooded	Minerotrophic	Carnation Sedge Fen	*Carex panicea, Cirsium dissectum, Carex hostiana*
Seasonally Flooded	Minerotrophic	Black Bogrush Fen	*Schoenus nigricans*
Seasonally Flooded	Minerotrophic	Wet Sedge-Horsetail Fen and Flush	*Carex vesicaria, Equisetum arvense, Caltha palustris, Eleocharis palustris*
Seasonally Flooded	Minerotrophic	Turlough Floor Meadow	*Carex viridula, Carex elata, Baldellia ranunculoides, Ranunculus flammula*
Semi-permanently Flooded	Minerotrophic	Sawsedge Fen	*Cladium mariscus*
Semi-permanently Flooded	Minerotrophic	Bulrush-Common Reed Reedswamp	*Schoenoplectus lacustris, Phragmites australis*
Semi-permanently Flooded	Minerotrophic	Sparsely Vegetated Marl Flat	*Litorella uniflora, Eleocharis multicaulis*
Permanently Flooded	Oligotrophic	Open Water (Aquatic)	NA

Figure 3. Major wetland community types of Burren National Park: a.) Raised Bog, b.) Flooded Limestone, c.) Carnation Sedge Fen, d.) Black Bogrush Fen, e.) Wet Sedge Fen and Flush, f.) Turlough Floor Meadow, g.) Sawsedge Fen, h.) Bulrush-Common Reed Reedswamp (along shoreline), i.) Sparsely Vegetated Marl Flat. All photos were taken by senior author.

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). The floristic classification recognized three temporarily flooded upper wetland community types that corresponded to two mapping units: *Raised Bog*, *Limestone Shrubland*, and *Limestone Meadow* (the latter was indistinguishable as a mapping unit and collectively forms the *Limestone Type*). Seasonally flooded types at intermediate elevations included *Carnation Sedge Fen*, *Black Bogrush Fen*, *Wet Sedge Fen and Flush*, and *Turlough Floor Meadow*. At the lowest relative elevations (i.e., the bottoms of the wetland basins), three types were recognized semipermanently and permanently flooded *Sawsedge Fen*, *Bulrush-Common Reed Reedswamp*, and *Sparsely Vegetated Marl Flat* (Table 1). The flora of the Park is composed of a matrix of perennial graminoids, with interspersed annual and perennial forbs that are often quite showy (Figure 4).

The supervised classification produced clear mapping units in the Park that were easily identifiable by color and texture in the original orthophoto and interpretable from field photos (Figure 5; embedded images in Figure 6). As an example of the mapping results, Figure 6 shows a tessellated digital map for the Skaghard-Coolorta-Travaun-Aughrim Wetland Complex, an interconnected set of wetland basins within the Park.

The major wetland complexes studied totaled over 520 ha, or approximately one third of the area of the entire park (Table 2). The wetland complexes are typically represented by a half dozen or more wetland types, and often with considerable open water habitat. In aggregate, the various fen types formed the largest share (48.9%) of wetland area. Raised Bog, in contrast, composed only 2% of the area, which is very unusual in far west Ireland. Turloughs and open water habitats each composed nearly a fifth of the Park. Turlough Floor Meadow was fairly extensive and easily recognizable, but it contained a floristically heterogeneous mosaic of marl flat, fen, and reedswamp plant spe-

cies. Reedswamp was a relatively minor element (1.1%), occurring only around permanent deepwater habitats, although Sawsedge Fen, characterized by 2 m high monotypic stands of sawsedge (*Cladium mariscus*), is arguably similar to reedswamp in form and distribution. Open water was largely centered in Lough Bunny, a large, shallow limestone lake. The Ballyeighter Peatland complex was the most heterogeneous and diverse wetland in the Park, containing all nine wetland vegetation mapping units, as well as considerable open water habitat (Table 2).

INTERPRETING BURREN NATIONAL PARK WETLANDS

This modest inventory and monitoring effort demonstrated that Burren National Park contains a number of distinctive and clearly recognizable community types. These elements are clues to a more holistic and dynamic interpretation of wetlands in BNP. This study, and especially the seminal wetland research of Dr. Michael Proctor over nearly five decades (Ivimey-Cook and Proctor 1966, Proctor 2010), suggest that the wetland landscape of BNP is an expression of diverse hydrologic, ecological, and human interactions over time. Within the BNP, Mullaghmore Mountain (Figure 1) forms both the visual centerpiece and the driving hydrogeomorphic feature, where orographic precipitation peaks, and where rains and occasional snows percolate downward to recharge the karst aquifers underlying the Park. Ground and surface water flow from the mountain southeast 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 and hydraulic conductivity yield considerable complexity in wetland hydrology. At highest elevations on the mountain slopes, fens predominate (Figures 3c, d, g, and e), due to consistent groundwater discharge. These fens yield steady flow into the larger turlough basins downslope (Figures 3f, i), 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, and lake surfaces are expressions of the local water table (Figure 1). 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 (Figure 2), the gradients in soil moisture and flood duration from edge to center were associated with relatively predict-

TABLE 2. AREA OF EACH MAPPING UNIT IN THE MAJOR WETLAND COMPLEXES OF BURREN NATIONAL PARK.

Mapping Unit	*Ballyeighter Peatland*	*Coolreash*	*Knockanroe*	*Skaghard Lough*	*Coolorta*	*Lough Awaddy / Aughrim Ponds*	*Lough Bunny*	*Lough Gealainn*	*All Wetland Complexes*	
	Area (ha)									Percent of Total Area
Wet Sedge Fen and Flush	1.9	2.9				0.1	8.9	0.5	14.3	2.7
Raised Bog	10.7								10.7	2.0
Carnation Sedge Fen	24.8	5.5	3.2	3.1	1.8	0.3			38.7	7.4
Black Bogrush Fen	112.6	0.5	9.3	8.5	14.5			5.0	150.4	28.8
Sawsedge Fen	26.5	0.9	0.1	2.0	8.3	1.1	12.1	1.5	52.3	10.0
Sparsely Vegetated Marl Flat	22.2		1.2		14.7	0.5		6.1	44.7	8.6
Flooded Limestone	10.6		5.6	3.6	16.4	0.4	9.1	2.2	48.0	9.2
Turlough Floor Meadow	17.0	1.7	8.2	7.7	13.4	0.4		5.6	54.1	10.3
Reed-Bulrush Reedswamp	1.3	0.0		0.9	1.5	0.7	0.5	0.7	5.5	1.1
Open Water	21.0	0.1	0.1	1.4	4.8	0.0	74.2	2.4	104.1	19.9
Cumulative Totals	**248.6**	**11.7**	**27.7**	**27.1**	**75.5**	**3.5**	**104.7**	**23.9**	**522.8**	**100.0**
Number of Vegetation Mapping Units	**9**	**6**	**6**	**6**	**7**	**7**	**4**	**7**		

Figure 4. Common wetland plant of Burren National Park: a) Tufted sedge (*Carex elata*), b) Early Marsh-orchid (*Dactylorhiza incarnata*), c) Black bog rush (*Schoenoplectus nigricans*), d) Tormentil (*Potentilla erecta*), e)Bog thistle (*Cirsium dissectum*), and f) Creeping buttercup (*Ranunculus repens*). All photos were taken by senior author.

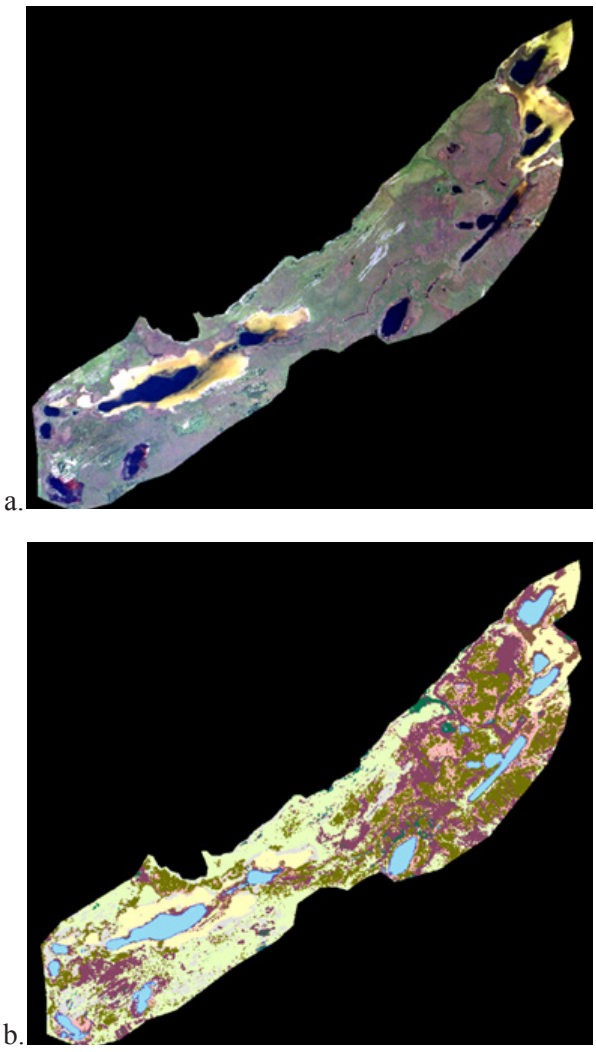

Figure 5. Image classification of Ballyeighter Peatland Complex: a) original orthophoto and b) ERDAS Imagine image classification.

able changes in plant community type. However, there appears to be considerable floristic overlap in many of the widespread types in the Park, suggesting that perhaps establishment effects or other factors play a role in the current distribution of the major types.

Proctor (2010) also suggests 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, such as Lough Gealáin and Ballyeighter. The delineation of relatively discrete mapping units, 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.

INVENTORY CONCLUSIONS

This collaborative mapping from approximately 5 weeks of fieldwork, with subsequent floristic and image analyses, provided a clear and interpretable wetland map for Burren National Park. A second visit was not possible, and the sample size was modest, so an accuracy assessment was not conducted. Therefore, this map must be viewed as a rapid assessment effort that would undoubtedly be improved with more detailed effort. Nonetheless, it provides an overview of the elements and distributions of the park wetland resources, and a number of new insights.

First, wetlands and lacustrine environments cover over one third of the total area of Burren National Park, and are composed of diverse landscape mosaics that are undoubtedly important for biodiversity. Second, the wetlands are dominated by fens, turloughs, and shallow limestone lakes, which are highly distinct in the larger region. In particular, the relatively large extent of turlough types suggests BNP is an ideal place for the study of these globally distinctive wetlands. Third, concurrent floristic and image

(orthophoto) classification can provide meaningful and information-rich wetland maps, if the number of types is modest and the boundaries between them fairly distinct, as they are at BNP. And finally, collaborative inventory and mapping efforts can provide excellent opportunities to learn about new wetland landscapes, while providing important new resources for park managers. ■

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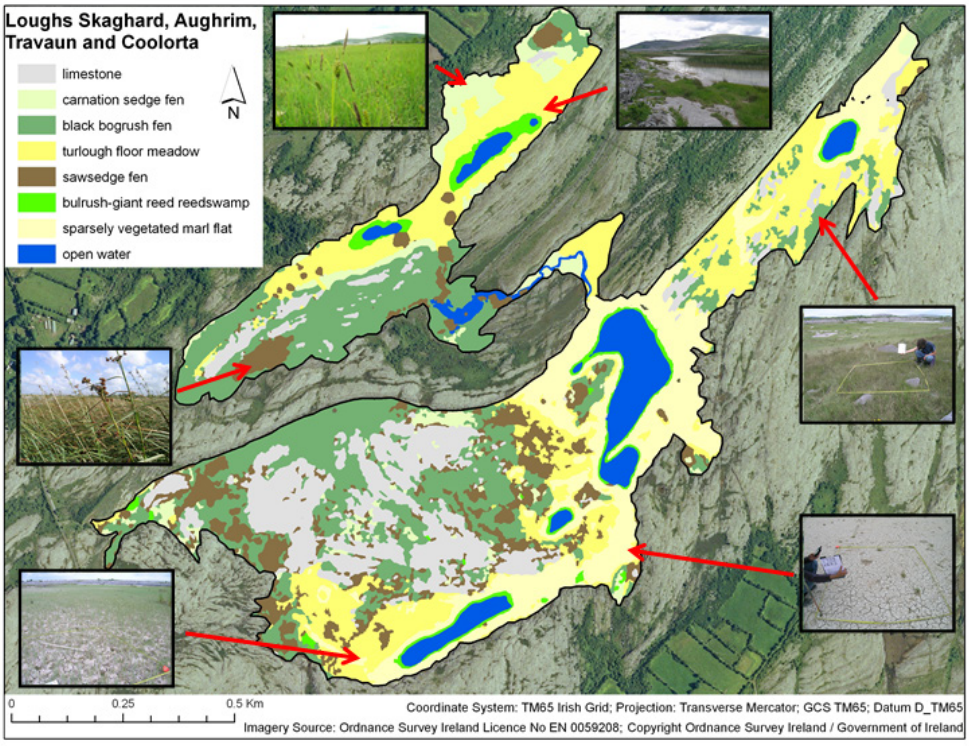

Figure 6. Overview of major wetland community types of the Skaghard-Travaun-Coolorta Turlough complex.