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Estimating conservation value and natural capital value of land cover classes in the Irish National Land Cover Map and application to a case study area

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Abstract

Conservation science and planning, by measuring proxies of biodiversity and ecosystem services provision, aim to identify priority areas for nature conservation and ecosystem services. In Ireland, fine-scale data on ecosystems functioning and biodiversity are limited, making it challenging to map conservation value (CV) and natural capital value (NCV) accurately. We elicited expert knowledge to rank habitat classes mapped in the recently published National Land Cover Map (NLCM) (EPA and Tailte Éireann, 2023). A scoring system from 0 to 10 was used to score habitats based on their estimated provision of biodiversity (CV) and ecosystem services (NCV). As a case study, we applied this scoring system to a catchment in the south-east of Ireland (>2,000 km²) with land cover information available from the draft NLCM. The expert elicitation showed little overall difference between the scores assigned by the team and the experts invited to validate the CV and NCV scores. However, some scores were revised based on experts' contributions. Results of the mapping exercise indicated a high correlation between monads with high CV and high NCV scores. Future work should focus on differentiating the weighting assigned to each ecosystem service associated with each land cover class. This could result in changes in the overall NCV scores assigned to each habitat (and monads). Nevertheless, the approach developed here has the potential to identify areas in the landscape that should be targeted for conservation. For reproducibility, we provide the R code for analysis at polygon scale.

Keywords

Agri-environment • biodiversity • ecosystem services • habitats • natural capital

Introduction

Conservation science and planning, by measuring proxies of biodiversity and ecosystem services provision, aims to identify priority areas for nature conservation and hotspots of ecosystem services. The new National Land Cover Map (NLCM) (EPA and Tailte Éireann, 2023) for the Republic of Ireland (Ireland) provides a detailed map of different land cover classes, and represents a significant opportunity to improve the predictive mapping of biodiversity and ecosystem service provision. Knowing the spatial distribution of habitat classes, and the level of biodiversity (reflecting its rarity and naturalness) and ecosystem service provision associated with each, one can estimate and compare the conservation value (CV) and natural capital value (NCV) across defined spatial units.

Quantifying the spatial distribution of CV and NCV first requires a definition of each. We adapted the definition of NCV from Maes *et al.* (2013), as follows: "The stock of natural assets that provide society with renewable and non-renewable resources and a flow of ecosystem services. It includes abiotic services, for example fossil fuels, minerals, metals and biotic assets, for example ecosystems that provide a flow of ecosystem services. These resources provide services – known as ecosystem services – such as air and water filtration, food production, pollination, climate and erosion control and recreational areas, which are essential to humankind's well-being. Thus, the more benefits a habitat produces the higher its NCV". We define CV as "The capacity of a site to maintain a certain number of species, vegetation groups, ecotypes or rare/threatened features. The CV of a habitat is based on the current average quality of the habitat, that is, lower habitat condition influences the CV. It relates to biodiversity (as in richness) or the capacity to retain rare species or to the rarity

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of the habitat. Thus, it is possible for a habitat with low species richness to have high CV" (adapted from Du Bus de Warnaffe & Devillez, 2002).

Different land cover classes (habitats) maintain different taxonomic groups and species, and provide different ecosystem services. These can be estimated (Rossi & Kuitunen, 1996; Hilli & Kuitunen, 2005) by assigning values (scores) on the basis of the potential or measured number of species, species rarity/conservation status (Rossi & Kuitunen, 1996; Räsänen *et al.*, 2015) and/or potential or measured provision of ecosystem services (e.g., Räsänen *et al.*, 2015; Maes *et al.*, 2018).

Quantifying the relative state of different habitat classes typically relies on extensive data collection (or collation of existing data) of biodiversity and a broad range of ecosystem services. In practice, such data are rarely available, or are not in a sharable format; even when data are available, they may not include the range of habitats that occur at a national scale, and biases in data collection can confound their interpretation (Parker *et al.*, 2016). In Ireland, fine-scale data on functioning and biodiversity of ecosystems are quite limited, making it challenging to accurately and consistently map CV and NCV with a repeatable methodology that is applicable at large spatial scales. One solution to overcome such data limitations is the use of expert knowledge that can integrate available knowledge where possible, and/or provide informed professional judgement where field data are limited (e.g., Carey *et al.*, 2003; Finn *et al.*, 2009; Martin *et al.*, 2012; Pearman-Gillman *et al.*, 2020).

This study aimed to elicit expert judgement to score the NCV and CV of all land cover (here, also "habitat") classes in the NLCM for Ireland (that provided spatial data on the extent and distribution of land cover classes). Using a set of scores for NCV and CV, these were applied to a case study area of the NLCM and illustrate variation at the scale of polygons and monads (1 km × 1 km). The methodology is described to ensure transparency and the underlying R code is provided so that it is repeatable. This work summarises a longer final report produced as part of the HNV_FarmForBio project (Ruas *et al.*, 2022).

Materials and methods

The land cover classes considered in this work, and corresponding definitions, were compiled from NLCM reference documents made available to members of the project team in 2022 (before the final release of the map in March 2023). An expert judgement and elicitation process, borrowing elements from both the nominal group and Delphi techniques, was developed to achieve a general agreement or convergence of expert opinions (McMillan *et al.*, 2016). A scoring system from 0 to 10 was used to relate different levels of CV to biodiversity (as in richness and/or presence of rare species and/or to the rarity of the habitat) or habitat rarity. A scoring system for NCV (also from 0 to 10) aimed to relate to the amount of natural assets that a habitat provides that result in benefits to the society (ecosystem services).

Looking at a schematic overview (Figure 1), the seven members of the HNV_FarmForBio project team (https://hnvfarmforbio.ie) first individually scored each habitat class for both CV and NCV. The team then engaged in discussion to reach a consensus (similar to the nominal group technique). In the second step, a validation exercise was conducted, that is, external experts (n = 34) based in Ireland were invited to review and rescore the CV and NCV scores that were assigned by the HNV_FarmForBio team. The external experts were selected based on their experience in environmental monitoring, agricultural management, nature conservation, biodiversity and landscape ecology. External experts were provided with background information and instructions and space to detail the reasons for any disagreements with the initial scores (particularly for deviations of ±2 points) (Figure A1 and see Ruas *et al.* [2022]) for a complete description of all NLCM habitats. A summary of the information provided was as follows:

(a) To standardise the scoring across different habitats, a 1 ha area of each habitat was considered (e.g., 1 ha of marine water or 1 ha of scrub).
(b) Habitat "quality" corresponded to the national average, informed by the EPA (2020) State of Environment Report.
(c) Habitats with innate low biodiversity (e.g., peatland) can have a high CV due to that habitat's rarity and naturalness.
(d) NCV scores refer to the habitat's resources that provide an array of ecosystem services. When scoring, the weight given to each ecosystem service should be the same (e.g., food production has the same value as carbon sequestration and storage). A list of the ecosystem services considered is provided in Appendix Table A1.

When scoring the NCV of a habitat, the potential disservices (negative or dangerous effects of ecosystems for the society) (Campagne *et al.*, 2018) were also considered.

The data from external experts were analysed using exploratory statistics. In the third step, the habitats with validation scores (expert's scoring) that deviated ±2 points from the initial CV/NCV score were considered by the project team – this was assessed for each expert reply separately. For habitats that deviated ±2 points from the initial CV/NCV score or that had different CV/NCV average, the justifications given by the expert were read and the CV/NCV score changed if the HNV_FarmForBio project team agreed with the expert's justification. A discussion by the project team was also conducted for those habitats with average CV/NCV score (average of all experts' scoring) deviating from the initial score by 1 point.

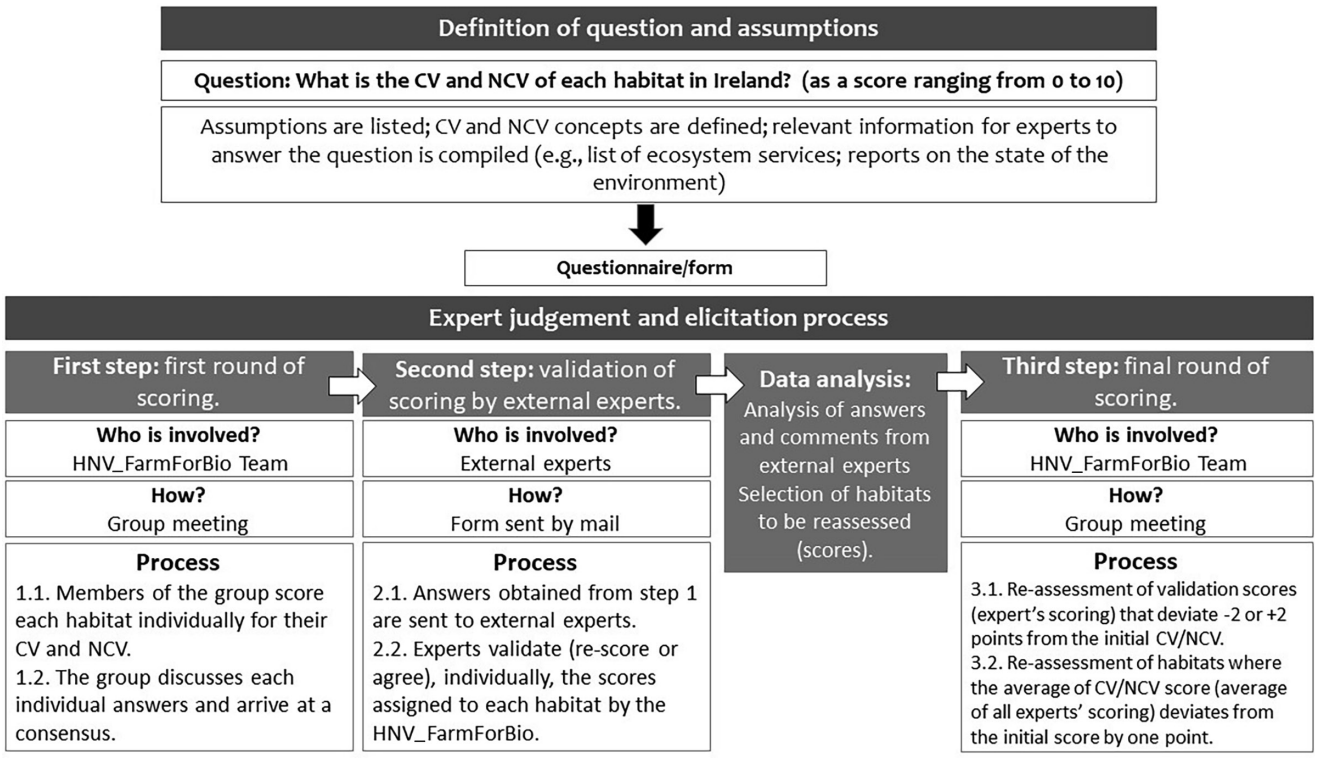

Figure 1. Schematic overview of the process for elicitation of expert judgement for scoring of habitat classes in Ireland for their conservation value (CV) and natural capital value (NCV).

Using the final (Table 1) CV and NCV scores, we assigned the scores to the habitat classes in each habitat/polygon mapped in a case study area of the NLCM, using a repeatable and transparent methodology for mapping CV and NCV. The case study area is a catchment (approximately 2,000 km^2) located in the south-east of Ireland (Figure 2). It corresponds to the "Slaney & Wexford Harbour" catchment and includes three Special Areas of Conservation (Blackstairs Mountains, Dublin Wicklow Mountains and Slaney River Valley SACs) and two Special Protection Areas (Wexford Harbour and Slobs and the Wicklow Mountains SPAs) (EPA, https://gis.epa.ie/EPAMaps/Water). Elevation ranges from 0 m to 920 m above sea level. All NLCM habitat classes are represented in this catchment, and the most represented habitats in the catchment are "improved grassland" (39.62%) and "cultivated land" (23.83%). The geometric accuracy of the final NLCM (the national dataset) is 87.2% and the thematic accuracy is 78.5% (EPA and Tailte Éireann, 2023). Note that this case study area was used because it was a validation area for which data were available to the project team in advance of the final NLCM dataset being publicly available. At the time we received the data, some polygons were classified as "Water_P2" (0.002 km^2 or 0.0001% of the case study area). We categorised "P2" as "rivers and streams" (final NLCM classification) in the case study.

An R script is provided (supplementary file) corresponding to two functions created by the HNV_FarmForBio project. For a data file from the NLCM, one function assigns the corresponding CV score to each NLCM polygon, and a second function assigns the NCV score to each polygon. Once each polygon (habitat) was scored, we intercepted the case study area with a grid of 1 km × 1 km (monad) and separately determined the weighted average for both CV and NCV per monad. A 1 km × 1 km grid was chosen following Carlier *et al.* (2023) for monitoring HNV farmland and forest (to enhance comparability) and generated in ArcGIS 10.5 using the tool Create Polygon Grid Wizard (ESRI, 2016). The national boundaries map was used to define the extent of the grid layer (coordinate system: EPSG:2157 – IRENET95/Irish Transverse Mercator).

The case study dataset allowed us to illustrate some of the possible comparisons and to illustrate the patterns that occur at a relatively fine scale of resolution. We applied a threshold value of 4.5 for both CV and NCV to distinguish between sets of monads that have values above or below this. This threshold was based on the middle of the scale of the

Table 1: Scores for natural capital value (NCV) and conservation value (CV) assigned to each habitat class by the HNV_FarmForBio team and by the experts (*n* = 10)

Habitat class	NCV team	NCV mean ± SD	NCV final	CV team	CV mean	CV final
Amenity grassland	3	3 ± 0.6	**3**	2	2 ± 0.4	**2**
Artificial surfaces	1	1 ± 0.5	**1**	1	1 ± 0.3	**1**
Artificial waterbodies	4	5 ± 0.9[1]	**5**	4	5 ± 1.1[1]	**5**
Bare peat	2	2 ± 0.9	**2**	0	0 ± 0.0	**0**
Bare soil and disturbed ground	2	2 ± 0.5	**2**	0	1 ± 1.5[1]	**2**
Blanket bog	9	9 ± 0.4	**9**	9	9 ± 0.4	**9**
Bracken	2	2 ± 1.0[1]	**2**	3	3 ± 1.0[1]	**3**
Broadleaved forest and woodland[2]	8	—	**8**	7	—	**7**
Broadleaf forestry[2]	7	7 ± 0.5	**—**	6	6 ± 0.5	**—**
Buildings	1	1 ± 0.3	**1**	1	1 ± 0.3	**1**
Burnt areas	2	2 ± 0.7	**2**	1	1 ± 0.5	**1**
Coniferous forest	5	5 ± 1.3[1]	**5**	3	3 ± 1.7[1]	**3**
Coastal sediments	4	5 ± 1.1[1]	**5**	6	6 ± 0.4	**6**
Cultivated land	4	4 ± 1.1[1]	**4**	2	2 ± 0.3	**2**
Cutover bog	3	3 ± 1.0[1]	**3**	3	3 ± 1.3[1]	**3**
Dry heath	7	7 ± 0.4	**7**	8	8 ± 0.7	**8**
Exposed rock sediments	5	5 ± 1.0[1]	**5**	6	6 ± 1.2[1]	**6**
Fens	8	8 ± 0.7	**8**	9	9 ± 0.3	**9**
Hedgerows	7	7 ± 0.3	**7**	6	6 ± 0.9	**6**
Improved grasslands	4	4 ± 0.6	**4**	3	3 ± 0.7	**3**
Lakes and ponds	7	7 ± 0.7	**7**	8	8 ± 0.5	**8**
Marine water	9	9 ± 0.4	**9**	8	8 ± 0.7	**8**
Mixed forest	6	6 ± 0.9	**6**	5	6 ± 0.7	**5**
Mudflats	7	7 ± 0.8	**7**	8	8 ± 0.8	**8**
Raised bog	9	9 ± 0.3	**9**	9	9 ± 0.3	**9**
Rivers and streams	8	8 ± 0.7	**8**	8	8 ± 0.7	**8**
Saltmarsh	7	7 ± 0.7	**7**	8	8 ± 0.7	**8**
Sand dunes	7	7 ± 0.7	**7**	8	8 ± 0.6	**8**
Scrub	6	6 ± 0.8	**6**	6	6 ± 1.1[1]	**6**
Semi-natural broadleaf[2]	9	9 ± 0.3	**—**	9	9 ± 0.3	**—**
Dry grassland	8	8 ± 0.4	**8**	8	8 ± 0.7	**8**
Wet grassland	7	8 ± 0.9[1]	**7**	8	8 ± 0.4	**8**
Swamp	7	8 ± 1.0[1]	**7**	7	7 ± 0.7	**7**
Transitional forest	5	6 ± 1.3[1]	**5**	5	5 ± 1.6[1]	**5**
Transitional water bodies	7	7 ± 1.0[1]	**7**	6	7 ± 1.3[1]	**7**
Treelines	7	7 ± 1.2[1]	**7**	6	6 ± 0.9	**6**
Ways	1	1 ± 0.3	**1**	0	0 ± 0.0	**0**
Wet heath	8	8 ± 0.0	**8**	8	8 ± 0.6	**8**

Experts' scores are reported as average (mean) and standard deviation (SD) of scores per habitat class. The final scores assigned to each habitat class (from the National Land Cover Map) for natural capital value (NCV) and conservation value (CV)) are in columns titled "NCV Final" and "CV Final" and highlighted in bold.
NLCM = National Land Cover Map.
[1]Difference ≥1 in either mean scores or SD value between experts' responses and the HNV_FarmForBio team.
[2]The early release of NLCM data used here had two separate land cover classes for "semi-natural broadleaf" and "broadleaf forestry" that were combined into "broadleaved forest and woodland" in the final NLCM data. Scores for the latter class were only allocated by the project team.

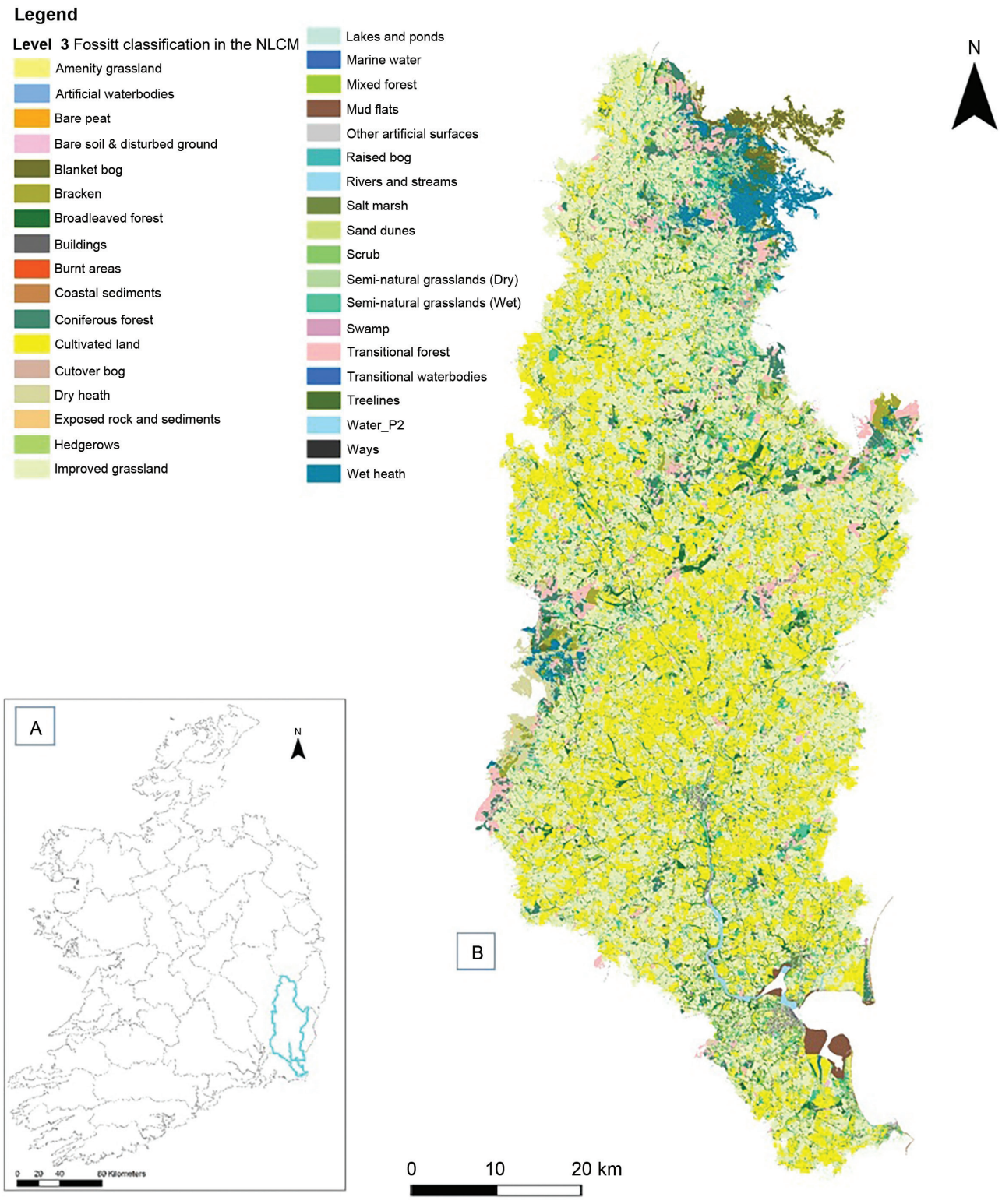

Figure 2. (A) Location of the case study area from the new National Land Cover Map (NLCM) in Ireland (outlined in blue); (B) Habitats mapped in the case study area from the new NLCM at level 3 of Fossitt (2000).

CV/NCV scores (0–9; no habitat was given a score = 10). These categorisations facilitated several comparisons.

Results

Of 34 external experts invited to contribute, 10 participated and had backgrounds that ranged from research/academia (*n* = 3); policy/public organisations (*n* = 3) and consultancy/practice (*n* = 4). In general, there was a high level of agreement between the initial scores provided by the HNV_FarmForBio team and the external experts (Table 1 and Figure 3).

Of the 37 land cover classes, there were very minor differences between the project team's score and the mean score of the external experts; the NCV scores differed for five classes (artificial waterbodies, coastal sediments, wet grassland, swamp and transitional forest) and the CV scores differed for four classes (artificial waterbodies, bare soil and disturbed ground, transitional waterbodies, mixed forest; Table 1). There were some differences between the HNV_FarmForBio team scores and those of the external experts (Appendix Table A2), and there was a difference of ≥2 points for 52 of the 740 elicited scores (10 experts and 37 land cover classes and both NCV and CV), with one expert (Expert 7, Appendix Table A2) contributing the majority of these differences. Averaging across the land cover classes for each external expert, the differences between the scores were, in general, <1 point (expert 7 being the exception) (Table 2). Following reassessment, the final set of NCV and CV scores per land cover class were agreed by the project team (Table 1).

Table 2: Average across all habitat classes of the difference in scores assigned by the HNV_FarmForBio team and that assigned by each of the 10 experts

Expert	Difference in NCV score	Difference in CV score
Expert 1	0.057	0.353
Expert 2	0.162	0.162
Expert 3	0.432	0.351
Expert 4	1.081	1.189
Expert 5	−0.05	−0.05
Expert 6	0.081	0.054
Expert 7	0.000	0.054
Expert 8	0.108	−0.027
Expert 9	0.108	0.108
Expert 10	−0.172	−0.097

CV = conservation value; NCV = natural capital value.

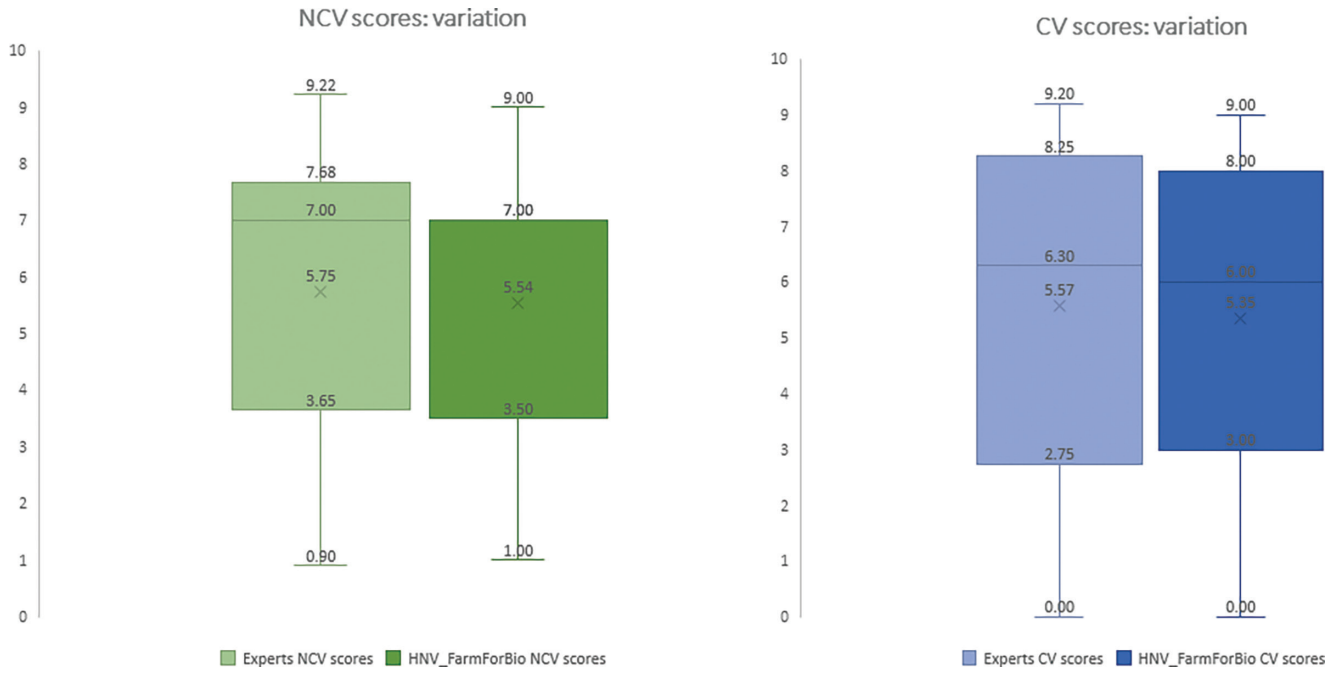

Figure 3. Summary of scores from the two groups of experts (HNV_FarmForBio team and external experts) for natural capital value (NCV) and conservation value (CV).

The land cover classes with the lowest score for NCV were "artificial surfaces", "buildings" and "ways" (NCV = 1); and the lowest for CV were "bare peat" and "ways" (CV = 0). No land cover class received a score of 10 for either NCV or CV but some scored 9 (Table 1). The habitat classes "blanket bog", "raised bog" and "semi-natural broadleaf" scored 9 for both NCV and CV. However, the "semi-natural broadleaf" class in the draft NLCM is not in the final NLCM, and the closest habitat class corresponds to "broadleaved forest and woodland", which scored 8.

The results for the case study area of the NLCM (south-east catchment) are presented as CV and NCV scores per monad (Figure 4A, B). Amidst a widely distributed dominance of cultivated land and improved grassland, there are distinct patches of wet heath and dry heath in the mid-west of the catchment, and a distinct area of wet heath, dry heath and peatland in the north-east (Figure 2). The high NCV and CV values of these areas are readily identifiable in Figure 4.

Categorising the monads by their distribution above and below the threshold value of 4.5 for NCV and CV, a total of

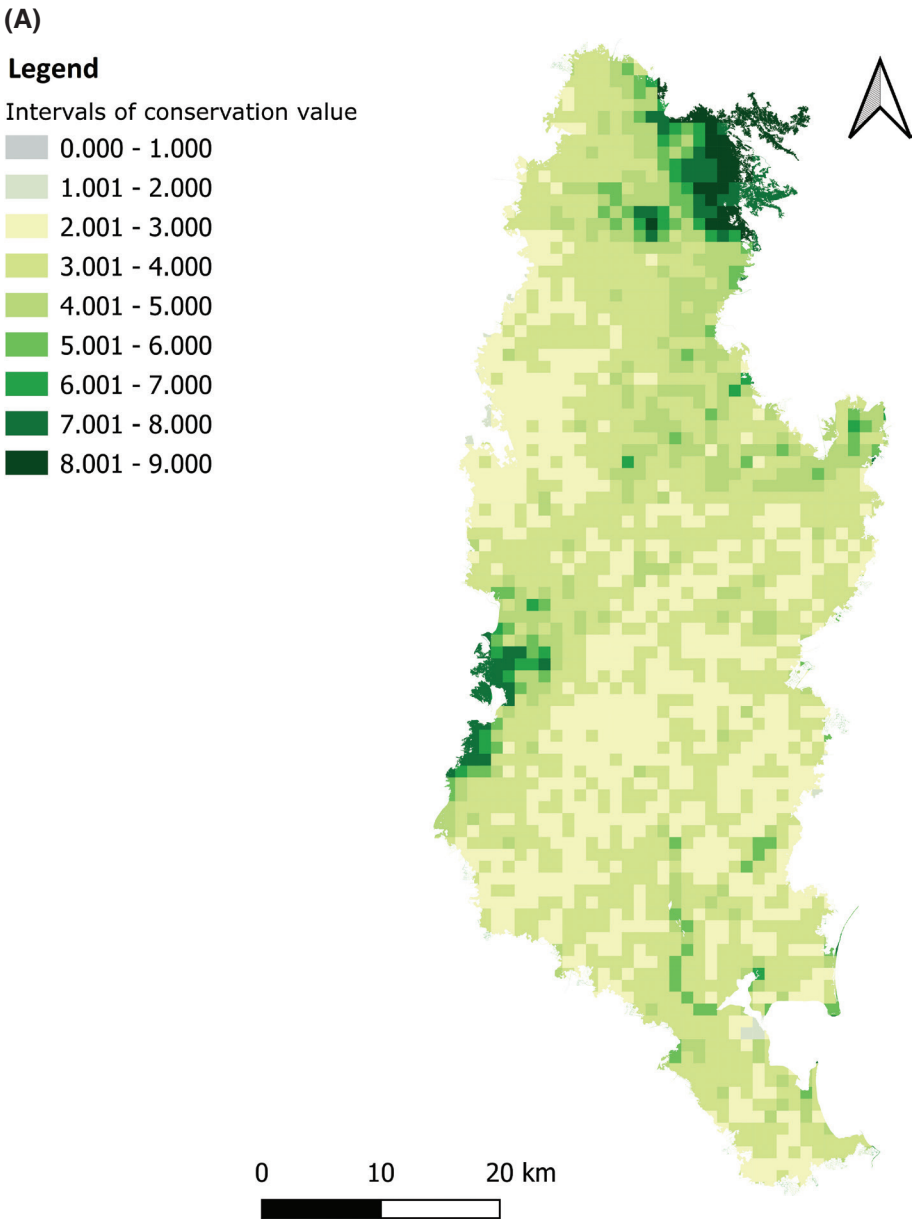

Figure 4. (continued)

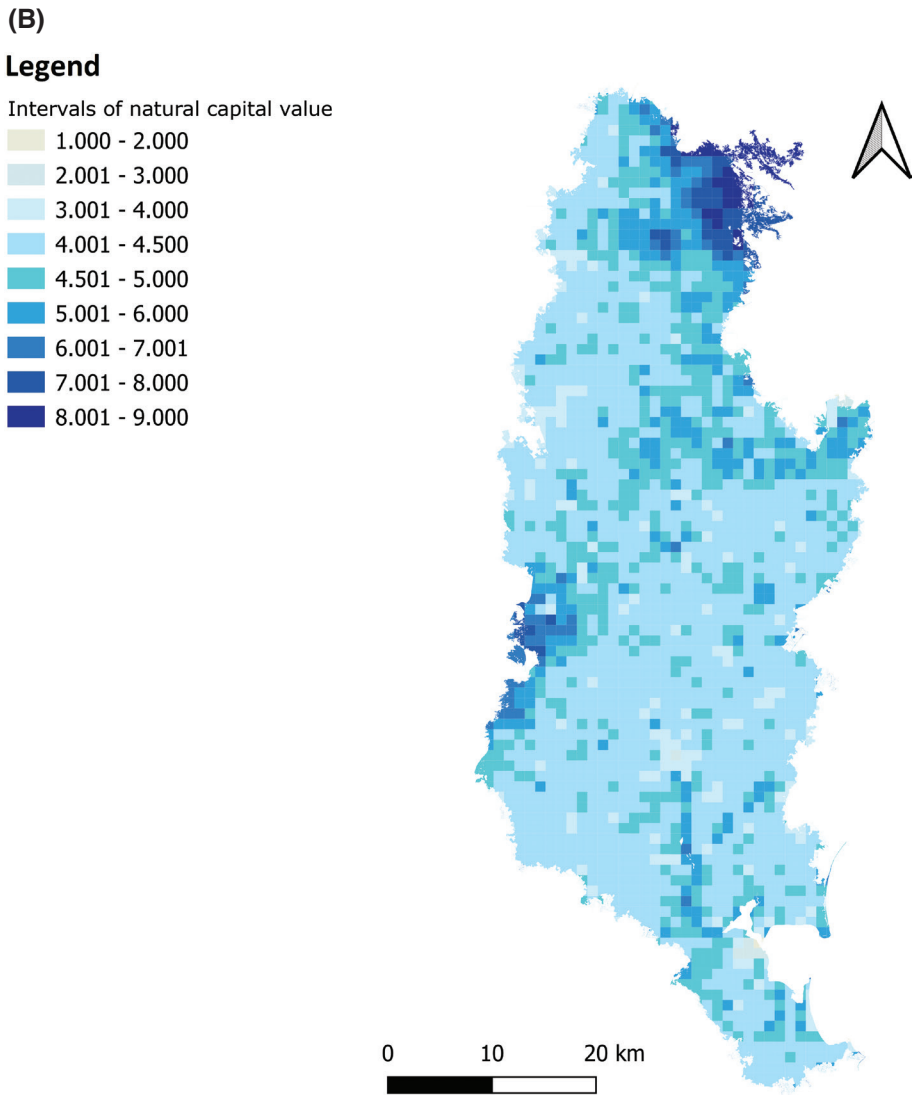

Figure 4. Case study area from the new National Land Cover Map (NLCM) in Ireland; with (A) conservation value mapped at monad scale (1 km × 1 km cell); and (B) natural capital value mapped at monad scale (1 km × 1 km cell).

424 monads had CV scores >4.5, of which 423 also had NCV scores >4.5 (Table 3). A total of 2,024 monads had CV scores ≤4.5, of which 537 monads had NCV >4.5. A total of 960 monads had NCV scores >4.5, while 424 monads had CV scores >4.5. Finally, a total of 1,484 monads had NCV scores ≤4.5, of which only 1 monad had CV score >4.5. Within this case study area, there was a very strong linear correlation between CV scores and NCV scores (ρ = 0.90, P < 0.01).

Discussion

We provided NCV and CV scores for land cover classes in the NLCM, and these can be used to inform spatial patterns in the extent and distribution of NCV and CV. This study found a strong positive correlation between CV and NCV (which indicates co-benefits), but care is required in the interpretation of this result. Crucially, there is a highly significant correlation (ρ = 0.95, P < 0.01) between the final scores for CV and NCV values across all land cover classes in Table 1; thus, any correlations using NLCM (or related) data are determined by the strong correlation among the final scores in Table 1. Nevertheless, from these preliminary results, and in the absence of other information, it seems more appropriate to target monads with higher CV values to identify geographical hotspots that also supply high levels of ecosystem services because: (a) most of the monads that have a high CV (>4.5) also have a high NCV (>4.5), and; (b) there is a considerable

Table 3: Summary table with results for conservation value (CV) and natural capital value (NCV) per monad (1 km × 1 km cell) for a sample area of the new NLCM (south-east catchment)

	Intervals	Number of monads per CV intervals in the case study area	Number of monads per NCV intervals in the case study area
(a)	0.01–1.00	17	17
	1.01–1.50	5	2
	1.51–2.00	15	5
	2.01–2.50	119	6
	2.51–3.00	639	4
	3.01–3.50	679	18
	3.51–4.00	364	163
	4.01–4.50	182	1,269
	4.51–5.00	117	497
	5.01–5.5	55	170
	5.51–6.00	61	70
	6.01–6.50	22	29
	6.51–7.00	15	70
	7.01–7.50	20	17
	7.51–8.00	66	49
	8.01–8.50	25	15
	8.51–9.00	43	43
	>9.01	0	0
(b)	Total number of monads mapped	2,444	2,444
	Monads with scores >4.5	424	960
	Total mapped area (ha)	210,391	210,391
	Mapped area with score >4.5 (ha)	27,631.82	77,636.58
	Percentage of mapped area with monads with score >4.5	13.13%	36.90%

NLCM = National Land Cover Map.

number of monads that have a high NCV (>4.5) that do not have a high CV (>4.5) – a total of 960 monads had NCV scores above 4.5, of which 536 monads did not have CV scores above 4.5.

Expert elicitation for environmental assessment

Where expert elicitation is used to express an uncertain quantity (that normally requires extensive and costly data collection), an assumption is that the experts possess the necessary understanding to account for various factors that will influence the value being assessed (Morgan, 2014). This is a typical limitation of such approaches, as it is difficult to guarantee that all participants have the same level of information to decide, and how exactly they arrived at the final result of this mental judgement. Because it is challenging to fully quantify all types of biases linked to expert elicitation, the provision of repeatable, transparent and structured protocols can improve its rigour (Hemming *et al.*, 2018).

To improve confidence in the process and the outcomes, the task presented to the experts in this study was clearly outlined, the main definitions and assumptions were listed and the subjectivity of responses was reduced through a quantitative scoring system – that is, there were no open replies or qualitative "high" or "low" response options (although the experts could add comments to explain their score values). Individually completed responses by the team members were collated and compared in advance of a group discussion (to minimise "groupthink"). Despite their diverse range of expertise, the difference between the team members and external experts was generally very low. The discussion of the experts' scores by the HNV_FarmForBio team members (stage 3 in Figure 1) aimed to resolve differences. For example, two of the invited experts proposed changing the CV of "exposed rock and sediments" from 6 to 8, adding the following comments "Limestone pavement are priority habitat" and "Like coastal sediments – undervalued but play a considerable role in terms of biodiversity and potentially geo-carbon"; while another expert proposed reducing the CV score from 6 to 4: "Based on my perception of the conservation value of exposed rocks and sediments it was not clear to me why such a high score had been assigned". In this instance ("exposed rock and sediments") the CV score = 6 was retained because both limestone pavements and coastal sediments are just two sub-classes of a wider range of sub-classes within this land cover class in the NLCM and the relative proportion of their area in the class should not be overestimated. These types of considerations were the focus of discussion in case of differences between the scores of the experts and the HNV_FarmForBio team.

Opportunities for future development of the methodology

Here, we highlight some caveats associated with the approach and, consequently, with the results of the study. First, and very importantly, the scores are intended to reflect the average state of a habitat class in Ireland. For example, priority habitats with good conservation status in EU Article 17 assessment would be expected to have a CV score = 10; however, most of such habitats do not attain good conservation status, and the CV scores are intended to reflect this. For specific locations, therefore, the score for a habitat class may under- or over-estimate the actual CV (or NCV) depending on whether its actual ecological condition is higher or lower than the average; clearly, with additional information, this is a significant source of potential improvement. Second, there are a number of sources of error associated with the

NLCM data. In addition to the known geometric and thematic accuracy estimates of the NLCM (see above), there is also a time lag between the NLCM (that is based on aerial imagery from 2018) and the present day. As one type of land cover is replaced by another over time, the inaccuracies associated with this will be cumulative over time. Thus, a regular update of the NLCM dataset using available ground-truthed and/or available satellite imagery/ortho-images will reduce inaccuracy associated with the NLCM. Third, although co-benefits can be expected, they do not necessarily occur. A counter-example is the strong negative correlation between provisioning services and biodiversity conservation (e.g., Nelson *et al.*, 2009). Räsänen *et al.* (2015), for example, found a low correlation between selected ecosystem services (carbon storage, timber production potential, landscape value for recreation) and CV, and cautioned, "… As different mapping approaches provide different maps, maps should be used with care". Fourth, the NCV scores represent an amalgamation of multiple ecosystem services and disservices into one single NCV score per land cover class. A separate scoring of each of the multiple ecosystem services would likely result in strongly differing levels of supply of ecosystem services not just between, but also within, land cover classes. This would also be highly likely to result in very different correlations between CV scores and scores for specific ecosystem services. A priority exercise would be to elaborate in more detail the provision from different land cover classes of more specific ecosystem services (and disservices) that comprise the NCV (as in Appendix Table A1). In our study, ecosystem services were assumed to have equal value. This is unlikely to correspond to reality, as some services may be more important (valued more) by society than others (Le Provost *et al.*, 2023; Neyret *et al.*, 2023). To define appropriate weights, it would be necessary to either (a) conduct an economic analyses of the value that society assigns to each ecosystem service using proxies such as the economic value of meat/milk/crops; price of carbon sequestration; the value of a "beautiful" landscape, etc., and generate a ranking based on monetary value or (b) conduct a comprehensive survey to rank or similarly indicate which ecosystem service is more valuable for society/human well-being. Fifth, the results obtained for NCV and CV scores in the case study area were not validated by us through ground-truthing or comparison with other available datasets. Overlapping of national-scale CV and NCV maps with other environmental data would improve identification of opportunities to validate the results of these approaches, and better identify the spatial coincidence of co-benefits between CV and NCV (with a greater focus on specific ecosystem services). For example, anonymised data collated through scoring of farmland habitats to assess ecological condition of several habitats at the plot/field level (e.g., woodland/scrubland; grasslands; peatlands and heathlands) in the new Agri-Environment Scheme (ACRES Co-operation; DAFM, 2021) could be used to contribute to an improvement of the methodology proposed here. Alternatively, other national-scale monitoring approaches could also be used to improve the methodology (Carlier *et al.*, 2021, 2023). In this work, we used the only information on habitat condition available (aggregated across several reports in EPA, 2020) which refers to habitats as a whole across the country, and there is no information at the monad or polygon levels. Thus, the scores obtained for CV and NCV could be revised using the information collated from scorecards and we can consider more detailed information for different polygons of the same land cover. This would provide a better understanding on the regional variability of CV and NCV. Until then, the methodology and results presented in this study can serve as a starting point to identify priority areas for nature conservation and hotspots of ecosystem services. One example of how the NLCM may not wholly represent ground-level features is the exclusion of linear features other than hedgerows and treelines. It omits some commonly occurring boundary types, for example, stone walls, drainage ditches and earth banks (Sullivan *et al.*, 2013) and this is likely to provide an incomplete picture of habitat diversity in landscapes (Matin *et al.*, 2020) and lead to artificially lower scores in areas dominated by linear habitats other than hedgerows (e.g., the Burren, Co. Clare and similar landscapes).

Adding value to the NLCM data

We provide a repeatable and transparent approach to map CV and NCV that can be applied to NLCM data. An R script was built and tested for a case study area and to reflect the data structure in the NLCM. These two functions can be applied directly to the NLCM and each polygon will be automatically scored. The methodology was only applied to one catchment in the south-east of Ireland and presented at the scale of individual polygons and monads; thus, the observed patterns and results are obviously not representative of the whole country. Depending on the objectives, the analysis and presentation of NLCM data at the scale of polygons (and monads) will be highly appropriate, and our code facilitates this.

Following completion of our research, the entire NLCM (EPA and Tailte Éireann, 2023) became publicly available and, for the first time in Ireland, provides the areal distribution of land cover classes (including many habitats) as small-scale objects. The availability of the NLCM data will likely result in an immediate need for scores of individual land cover classes that can facilitate an inventory of estimated CV and NCV (or related metrics) for different spatial units (e.g., monads, tetrads, river catchments, electoral districts). With the NCV and CV scores of different habitat classes provided here, a range of applications are made possible that can improve

predictive mapping and comparisons. Such use of NLCM data can still offer significant improvements over existing methods and limited data availability. In the years ahead, we anticipate a rich new research effort that can use the NLCM data to better improve such models of the distribution and quality of HNV farmland, and to better use NLCM data to track temporal changes in land cover classes associated with wildlife habitats.

Acknowledgements

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Data availability statement

The data that were used as part of the case study are publicly available as part of the NLCM. The code used to analyse these data is publicly available on figshare at: https://doi.org/10.6084/m9.figshare.25334470.v1.

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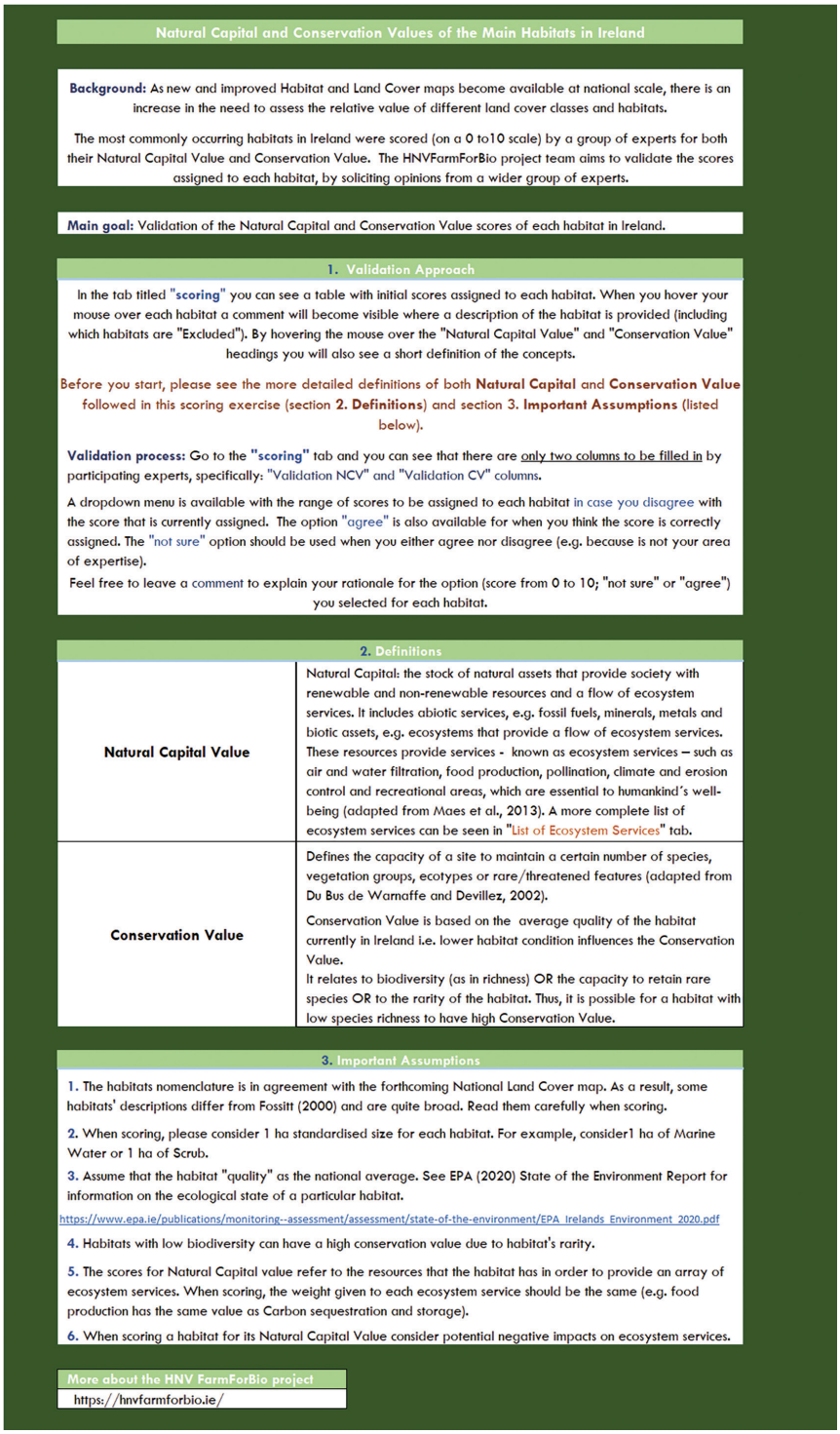
Appendix



Natural Capital and Conservation Values of the Main Habitats in Ireland

Background: As new and improved Habitat and Land Cover maps become available at national scale, there is an increase in the need to assess the relative value of different land cover classes and habitats.

The most commonly occurring habitats in Ireland were scored (on a 0 to10 scale) by a group of experts for both their Natural Capital Value and Conservation Value. The HNVFarmForBio project team aims to validate the scores assigned to each habitat, by soliciting opinions from a wider group of experts.

Main goal: Validation of the Natural Capital and Conservation Value scores of each habitat in Ireland.

1. Validation Approach

In the tab titled "**scoring**" you can see a table with initial scores assigned to each habitat. When you hover your mouse over each habitat a comment will become visible where a description of the habitat is provided (including which habitats are "Excluded"). By hovering the mouse over the "Natural Capital Value" and "Conservation Value" headings you will also see a short definition of the concepts.

Before you start, please see the more detailed definitions of both **Natural Capital** and **Conservation Value** followed in this scoring exercise (section **2. Definitions**) and section 3. **Important Assumptions** (listed below).

Validation process: Go to the "**scoring**" tab and you can see that there are only two columns to be filled in by participating experts, specifically: "Validation NCV" and "Validation CV" columns.

A dropdown menu is available with the range of scores to be assigned to each habitat in case you disagree with the score that is currently assigned. The option "agree" is also available for when you think the score is correctly assigned. The "not sure" option should be used when you either agree nor disagree (e.g. because is not your area of expertise).

Feel free to leave a comment to explain your rationale for the option (score from 0 to 10; "not sure" or "agree") you selected for each habitat.

2. Definitions

Natural Capital Value	Natural Capital: the stock of natural assets that provide society with renewable and non-renewable resources and a flow of ecosystem services. It includes abiotic services, e.g. fossil fuels, minerals, metals and biotic assets, e.g. ecosystems that provide a flow of ecosystem services. These resources provide services - known as ecosystem services – such as air and water filtration, food production, pollination, climate and erosion control and recreational areas, which are essential to humankind's well-being (adapted from Maes et al., 2013). A more complete list of ecosystem services can be seen in "List of Ecosystem Services" tab.
Conservation Value	Defines the capacity of a site to maintain a certain number of species, vegetation groups, ecotypes or rare/threatened features (adapted from Du Bus de Warnaffe and Devillez, 2002). Conservation Value is based on the average quality of the habitat currently in Ireland i.e. lower habitat condition influences the Conservation Value. It relates to biodiversity (as in richness) OR the capacity to retain rare species OR to the rarity of the habitat. Thus, it is possible for a habitat with low species richness to have high Conservation Value.

3. Important Assumptions

1. The habitats nomenclature is in agreement with the forthcoming National Land Cover map. As a result, some habitats' descriptions differ from Fossitt (2000) and are quite broad. Read them carefully when scoring.
2. When scoring, please consider 1 ha standardised size for each habitat. For example, consider1 ha of Marine Water or 1 ha of Scrub.
3. Assume that the habitat "quality" as the national average. See EPA (2020) State of the Environment Report for information on the ecological state of a particular habitat.

https://www.epa.ie/publications/monitoring--assessment/assessment/state-of-the-environment/EPA_Irelands_Environment_2020.pdf

4. Habitats with low biodiversity can have a high conservation value due to habitat's rarity.
5. The scores for Natural Capital value refer to the resources that the habitat has in order to provide an array of ecosystem services. When scoring, the weight given to each ecosystem service should be the same (e.g. food production has the same value as Carbon sequestration and storage).
6. When scoring a habitat for its Natural Capital Value consider potential negative impacts on ecosystem services.

More about the HNV FarmForBio project

https://hnvfarmforbio.ie/

Figure A1. Instructions sent to experts invited to validate the scores (conservation and natural capital values) assigned to all National Land Cover Map habitats.

Appendix Table A1: List of the most commonly assessed ecosystem services (Common International Classification of Ecosystem Services [CICES] classification) to be considered when scoring a habitat for its natural capital value (NCV)

Provisioning services
Food
Wood and fibre
Water (irrigation and drinking)
Medicinal resources
Ornamental resources
Minerals and Soil
Genetic resources
Regulation and maintenance
Carbon sequestration and storage
Flood control/water regulation
Temperature control (shade, air corridors)
Erosion regulation
Water purification/waste treatment
Air quality
Soil quality
Life cycle maintenance
Noise reduction
Cultural services
Recreation
Tourism
Spiritual/religious value
Educational
Aesthetics and inspirational
Heritage/sense of place
Psychological/health/well-being

Appendix Table A2: List of habitats reassessed for either their conservation value (CV) or natural capital value (NCV) by the HNV_FarmForBio for deviating ± 2 points (expert scoring) from the score assigned by the HNV_FarmForBio team

Habitats list	Team NCV score	Expert validation NCV	Team CV score	Expert validation CV	Comments from survey respondents
Expert 1					
Bracken	2	5	3	5	Provides significant cover for small mammals.
Coniferous forest	5	8	3	7	Depends on management (e.g., monocultural or not; thinned or not; rotation based or Continuous Cover Forestry) and stage of development (semi-mature or mature).
Mixed forest	6	8	5	7	Depends on management (e.g., thinned or not; rotation based or Continuous Cover Forestry) and stage of development (semi-mature or mature or mixed age).
Transitional forest	5	8	5	6	My experience is that the ecological value of such areas is high as there is generally very little disturbance in these areas for up to 15–20 years and for large parts of that there is considerable cover, insulation, feeding, etc. I am adjusting the conservation value down to "6" as this is a dynamic process and not generally sustained.
Expert 2					
Artificial waterbodies	4	6	4	6	There are a couple of interesting examples that I would like to bring the authors attention to. Inland Fisheries Ireland reports confirm the Cong Canal as an important spawning habitat for Lough Mask ferox trout (*Salmo ferox*) (and the artificial waterbody mimics intermittent rivers in its other characteristics). Noel Wilkins (Ponds *et al.*, 1989) has a nice example of the cutting of a "new stream" in Connemara. I've not assessed the latter yet, but presume it may well now have characteristics that make it hard to distinguish from a natural watercourse. The case of the Broads is a classic example in England and perhaps we also have some less dramatic examples in Ireland. John Feehan refers to altered/new watercourses (Clare Island, 2019) and artificial gravel pits/constructed lakes for, for example, recreational fisheries. This is the rationale for indicating slightly higher scores, although it is accepted that these habitats can also prove problematic/negative for conservation, for example, disturbed habitats favouring introduced species, etc.
Expert 3					
Artificial waterbodies	4	5	4	6	These systems can be really important for aquatic macrophytes and invertebrates especially beetles and water bugs. They also act as important connectivity linkages for plants and animals especially in the midlands.
Bare soil and disturbed ground	2	Agree	0	2	Disturbed ground can encourage pioneering plant species to establish and allow a site to recover.
Coniferous forest	5	Agree	3	6	Mature sites can be home to high species richness of liverworts, lichens and mosses and also terrestrial and aquatic fungi.
Expert 4					
Artificial waterbodies	4	6	4	6	Variation within this category but some areas very good.
Expert 5					
Exposed rock and sediments	5	Agree	6	8	Limestone pavement priority habitat.
Expert 6					
Exposed rock and sediments	5	4	6	4	Based on my perception of the Conservation Value of exposed rocks and sediments it was not clear to me why such a high score had been assigned. That is a reflection perhaps of my limited knowledge of the ecology of such systems. I am happy to change that either to a 5 or 6, as it is not my area of expertise.

Appendix Table A2: (continued)

Habitats list	Team NCV score	Expert validation NCV	Team CV score	Expert validation CV	Comments from survey respondents
Expert 7					
Bare peat	2	0	0	0	No ecosystem services flow, no NCV.
Bare soil and disturbed ground	2	Agree	0	4	CV can be high where used by ruderal species and nesting birds.
Bracken	2	1	3	1	Has potential.
Burnt areas	2	0	1	0	No value at all really.
Costal sediments	4	7	6	7	These have a lot more value in terms of carbon filtration – less obvious from biodiversity perspective but generally undervalued I would say.
Cultivated land	4	7	2	Agree	High in provisioning services and if managed well can deliver for an array of services particularly biodiversity (think Corncrake!)
Cutover bog	3	6	3	7	Where regenerated to high nature value mosaics can be high value!
Dry heath	7	Agree	8	10	This is an Annex I habitat!
Exposed rock and sediments	5	8	6	8	Like coastal sediments – undervalued but play a considerable role in terms of biodiversity and potentially geo-carbon.
Fens	8	10	9	10	Undervalued, high biodiversity value and deliver an array of services. These pockets remaining are highly valuable.
Improved grasslands	4	5	3	1	Is this a personal bias but rye grass swards are low on my conservation value list!
Lakes and ponds	7	9	8	9	High value in terms of services across water, climate, biodiversity and a heap of other stuff we don't know yet.
Marine water	9	10	8	10	As above.
Mudflats	7	9	8	10	As for coastal sediments.
Rivers and streams	8	10	8	10	As for lakes and ponds.
Salt marsh	7	9	8	10	As for coastal sediments and mudflats.
Sand dunes	7	9	8	10	As above – think coastal protection as well.
Scrub	6	8	6	9	Highly undervalued but depends on type.
Dry grassland	8	9	8	10	Annex I habitats.
Wet grassland	7	9	8	9	Annex I habitats.
Swamp	7	10	7	9	As with fens.
Transitional forest	5	8	5	9	Transitional habitats are undervalued and serve vital functions for biodiversity.
Transitional waterbodies	7	10	6	10	As above.
Treelines	7	10	6	9	I could probably score this one down here to match the other scoring.
Wet heath	8	Agree	8	10	Annex I habitat!