The costs of peatland restoration revisited

March 2022 update on database based on the Peatland Action Programme in Scotland

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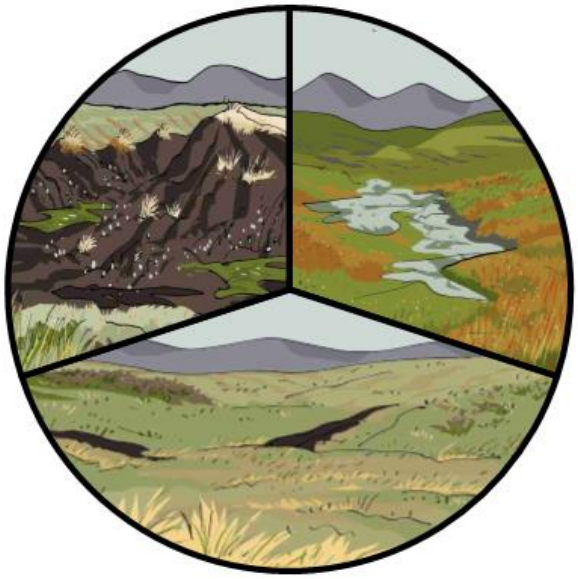

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Summary and key findings

1. This report provides an update of the Glenk et al. (2020, 2021) reports. The update is based on additional data entered into a database of peatland restoration activities and their costs, using data collected as part of the grant application and reporting process for the Peatland Action Programme (PAP) in Scotland.
2. The database includes information from 142 unique projects covering 323 restoration sites in Scotland, of which **data from 300 sites was suitable for the analysis**. We separately consider information from two types of forms completed by applicants and grantees: application forms (AF) and final reporting forms (FF).
3. Restoration activities were broadly categorised into five main categories: A) Ditch (grip) blocking; B) Hag, gully and bare peat restoration; C) Bunding; D) Forest to bog restoration; and E) Scrub removal.
4. More than half of the restoration sites in the database have a site designation, such as SSSI or NNR.
5. In terms of current use, **deer management (49%) and rough grazing (41%) rare most frequently mentioned as productive uses**, followed by field sports and forestry. **Biodiversity conservation was reported as the current use of the sites in 39% of cases**.
6. Across all AF, the mean estimate of restoration cost per hectare is £1896 (median: £1205). **The corresponding estimate of restoration cost per hectare across all FF is lower at £1712 (median: £1026)**. A number of outliers at the upper and lower end of the cost per hectare distribution dominate mean estimates. Dropping the highest and lowest 5% of cost per hectare estimates, values for AF are £1656 (mean) and £1203 (median); and values for FF are £1209 (mean) and £1026 (median).
7. **Restoration cost per hectare is approximately twice as high in the presence of forest-to-bog restoration relative to the absence of such activities**.
8. There is systematic variation in restoration costs by activity. Due to many unobservable factors affecting restoration cost, there will be limitations to the explanatory power of models of restoration cost. Nevertheless, a greater set of site characteristics and spatial variables should be considered to improve the explanatory power of models of restoration cost. Using spatial information on restoration sites will provide options to link cost data to information on peatland condition and associated greenhouse gas emission balances. This can serve as the basis for cost-effectiveness estimations.

Background

1. In this report, we update figures from previous reports (Glenk et al. 2020; 2021) on peatland restoration cost based on data collected as part of the Peatland Action Programme (PAP).
2. The previous reports can be found on the SEFARI webpage: https://sefari.scot/research/the-cost-of-peatland-restoration-in-scotland.
3. Our update is based on another batch of additional data, which going forward will enhance the robustness of the analysis. For the purpose of this report, we closely follow the structure of the initial Glenk et al. (2021) report. This means that we will keep the Section structure and numbering of Tables and Figures, making the report directly comparable with previously reported estimates.
4. We refer the reader to the initial Glenk et al. (2020) report for detailed background information, and a more detailed account of the structure of the data and the interpretation of findings.
5. The initial database was collated by researchers of SRUC, the James Hutton Institute and the University of Leeds using data collected as part of the grant application and reporting process for the PAP, funded by Scottish Government and administered by Scottish Natural Heritage (SNH), between 2016 and 2019 (https://www.nature.scot/climate-change/taking-action/peatland-action). The update, involving researchers of SRUC and the University of Leeds, includes more recent data from the 2019/20 and 20/21 PAP funding rounds.
6. The authors wish to acknowledge and highlight that data collection was greatly facilitated through collaboration between SRUC, James Hutton Institute, the University of Leeds and the SNH Peatland Action coordination and data management team. The process of data collection on restoration costs based on PAP and the potential use of the data is outlined in greater detail in Glenk et al. (2019).

Overview of information in database and important caveats

This Section summarises the information in the database, as well as key assumptions applied when building the database, and resulting caveats for analysis and interpretation.

1. In this report, we consider information from two types of forms completed by applicants and grantees of the PAP: application forms, prior to any restoration, and final reporting forms, to be completed after completion of restoration works (typically at the end of the financial year). The application form includes a description the planned restoration activities and estimation of all restoration costs (including cash and in-kind costs) for the project. The final reporting forms include details about the actual restoration activities and all costs actually incurred as part of the restoration project, in case they differ from activities or costs included in the application form.
2. The application form includes an amendment that provides 'monitoring information', which includes some basic information on applicants and their main views and motivations for undertaking peatland restoration. Data of these forms was entered (N=122) but will not be analysed here. We will also not consider similar information on grantees' experience that was collected as part of the final reporting.
3. In total, information from 142 unique applications was processed. An application is considered unique if it is submitted in a separate form (typically relating to projects in different locations), or if it is submitted in a different funding year for the same general location.
4. Of these 142 unique applications, 53 provided information from the application form only, 84 provided information from both application and final reporting forms, and 5 provided information only from the final reporting form.
5. We will henceforth refer to application forms as AF, and final reporting forms as FF.

6. One form may refer to one or several specific project sites for activities, which may be restoration or non-restoration (e.g. public engagement) activities. In total, there are 481 records entered into the database; 280 stemming from application forms, and 201 from final reporting forms.
7. The 481 records relate to 323 unique restoration sites; in 142 cases, records refer to the same restoration site in both application and final reporting forms. Final form information is available for almost two thirds of the 323 unique sites (for 204 sites).
8. We will henceforth refer to restoration sites entered based on application forms as AFS, and restoration sites entered based on final reporting forms as FFS. AFS and FFS will be analysed separately.
9. For a restoration site based on AF or FF to be included in the subsequent analysis, the minimum information requirement was area restored and total restoration costs. Of the 481 records which were entered, 41 records were dropped for analysis either because i) they do not relate to restoration activities, or because ii) information on costs or area was missing (i.e., minimum requirements are not met). **This results in 442 records from 300 unique sites for analysis.**
10. For inclusion in spatial analysis forms also needed to provide the grid reference for the restoration sites, and the reference had to fall within Scotland (i.e. not be an obvious error). See Figures 1 and 2 for the spatial distribution of these sites, and Appendix A for differences between 'located' and 'unlocated' sites.
11. Records for analysis in the database covering programme years 2016/17 (AFS: N=4; FFS: N=1), 2017/18 (AFS: N=107; FFS: N=51), 2018/19 (AFS: N=83; FFS: N=59), 2019/20 (AFS: N=57; FFS: N=46) , 2020/21 (AFS: N=17; FFS: N=17).
12. The following list summarises some of the main assumptions and limitations associated with the preparation of the database:
    a. The application and reporting forms changed between, and sometimes during, funding years, to account for changes in restoration practice and to gather additional information which will assist future monitoring. This represents a challenge for aligning information across years and across AF and FF for the same applicants.
    b. There is a wide range of approaches that applicants and grantees have taken to complete the forms. This leads to missing information, and often a need to infer activities reported and associated costs. We kept a log of all issues emerging during data entry (a 50-page plus word document). In many cases, we used our own judgement to, for example, allocate stated activities to pre-defined restoration techniques, or to allocate cost to activities. It was important for us to be consistent in our approach to allocating and interpreting information from AF and FF, but we cannot rule out the possibility that an external person may have a different interpretation, resulting in different allocations.
    c. Some forms list costs that refer to multiple restoration sites. These often but not exclusively refer to project management costs (including e.g. peat depth surveys and monitoring) and mobilisation costs. These multi-site costs were allocated based on the reported size of the restoration sites. Actual allocations may have differed; for example, a smaller site may actually have drawn more attention/a larger share of multi-site costs than a larger site.
    d. Some forms list in-kind (IK) contributions and their value. In many cases, in-kind costs were not allocated to specific sites. We used the same approach as for multi-site costs (allocation by area).
    e. Costs assigned to non-site activities, such as engagement activities, were not included unless they were (erroneously) referring to actual restoration activities.
    f. Several of the application forms list estimated costs for year 2 and 3, while funding in PAP was only granted on an annual basis. Since we are interested in analysing variation in

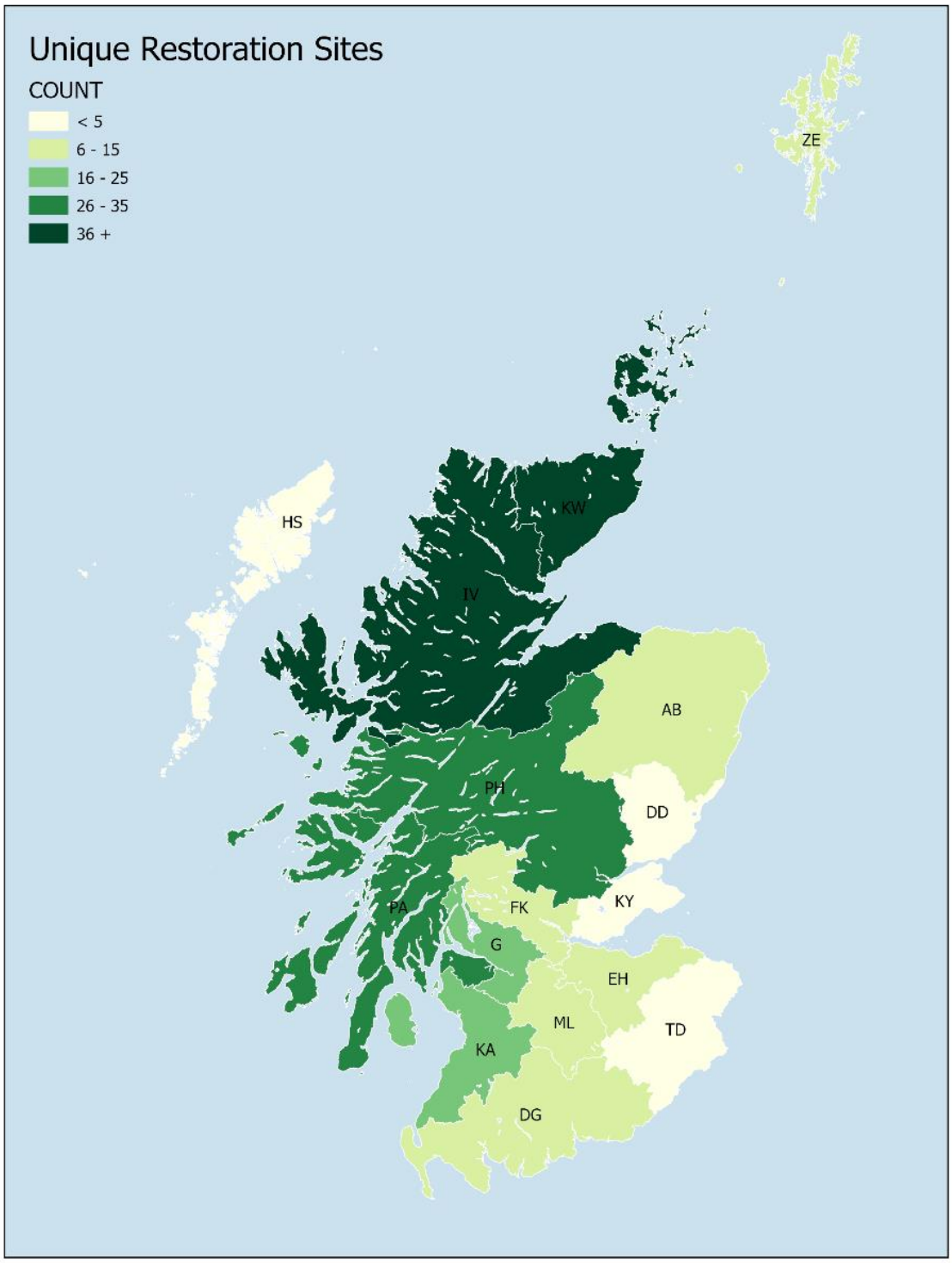
costs, we merged such costs (and associated activities) with activities taking place in year 1 (if any). Costs for years 2 and 3 are often proxy estimates and not based on quotes.

g. In a few occasions information on cost or area was missing in the FF and was therefore taken from the AF if present. Care was taken that this was only applied when the FF makes explicit mention of no change against the AF.

h. In a few cases, sites in the FF could not be unambiguously matched with sites listed in the AF. We assigned new site ID values in such cases.

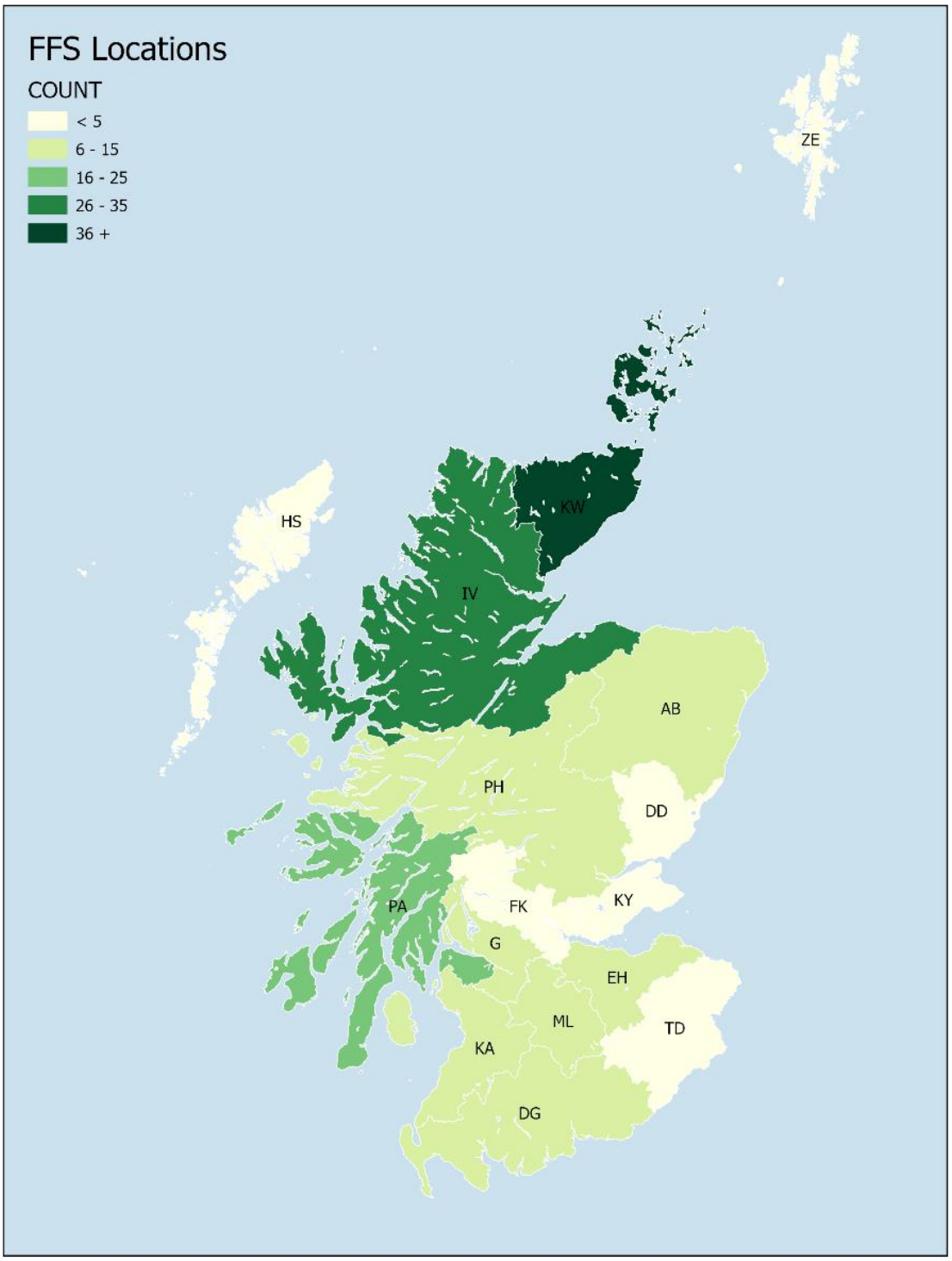
i. Project management (PM) costs were summarised in a single category. This lumps together a wide variety of items or activities, ranging from travel and subsistence to peat depth surveys and monitoring information. In a few cases, PM costs are listed in the forms to include mobilisation costs or costs of equipment. We retained some of these as PM costs, where they could not be otherwise assigned. Reported values of PM costs thus rather represent an upper bound of PM costs that overall includes a broad array of restoration-related items.

j. Related to point h. above, several forms do not provide a cost breakdown by activity, and/or by site. Thus, we cannot isolate PM costs for all applications and sites. If there is no breakdown of costs by site, costs were allocated by site area. This, of course, can only serve as a crude approximation of actual site PM costs.



Unique restoration site locations aggregated by postcode area.
AB (Aberdeen), DD (Dundee), DG (Dumfries), EH (Edinburgh), FK (Falkirk), G (Glasgow), HS (Comhairle nan Eilean Siar), IV (Inverness), KA (Kilmarnock), KW (Kirkwall), KY (Kirkaldy), ML (Motherwell), PA (Paisley), PH (Perth), TD (Galashiels), ZE (Shetland). Produced in ArcGIS Pro.

Figure 1. Unique restoration site locations aggregated by postcode area, including both AF and FF.



FFS locations aggregated by postcode area.
AB (Aberdeen), DD (Dundee), DG (Dumfries), EH (Edinburgh), FK (Falkirk), G (Glasgow), HS (Comhairle nan Eilean Siar), IV (Inverness), KA (Kilmarnock), KW (Kirkwall), KY (Kirkaldy), ML (Motherwell), PA (Paisley), PH (Perth), TD (Galashiels), ZE (Shetland). Produced in ArcGIS Pro.

Figure 2. FFS locations aggregated by postcode area.

Restoration activities

This Section concerns how restoration activities were categorised in the database, and what this means for estimation of restoration costs.

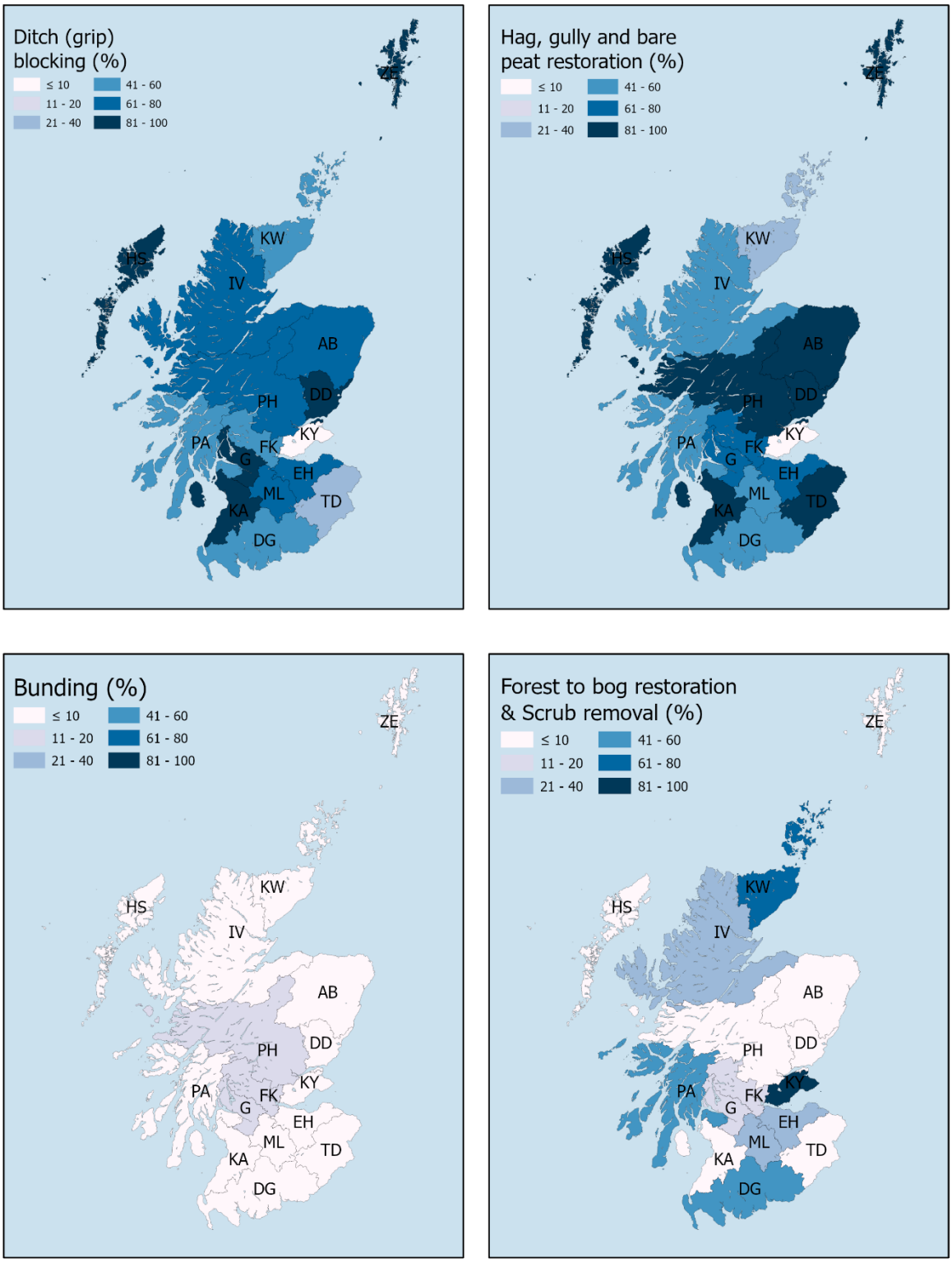
1. Under restoration activities we summarise all on-site restoration actions, i.e., changes made on a site with the aim of restoring peatlands. For a summary of techniques and associated effects on ecosystem services see Artz et al. (2018).
2. The restoration activities listed as default options for applicants and grantees on AFs and FFs differ across the years (16/17; 17/18; 18/19; 19/20; 20/21) due to changes that have been made to the forms.
3. In addition, the same type of restoration activities have not always been reported on consistently between AF and FF for a single project. This includes how applicants and grantees refer to certain restoration actions in the AF and FF for a single site, and the units that describe the extent of each activity (i.e., number of items vs. length/width vs. area covered by activities such as dams or ditches blocked).
4. Points 2 and 3 do not refer to differences between AF and FF resulting from changes in activity between application and carrying out the work.
5. In some AF and FF, a cost breakdown by activity is not provided, or does not refer to the types of activities listed, or lumps several activities together, for example for sites but not differentiated by activity.
6. Given the above, detailed questioning of the database to infer costs/unit of specific restoration activities is possible, but not without carefully assessing each considered AF/FF for consistency and reliability with respect to allocation of costs to (extent of) activities. We will therefore <u>not</u> provide information on (costs of) specific restoration activities in the report, but could provide such data and commentary if required.

Table 1. Categorisation of restoration activities.

	A **Ditch (grip) blocking**	**B** **Hag, gully & bare peat restoration**	**C** **Bunding**	**D** **Forest to bog restoration**	**E** **Scrub removal**
1	Ditch blocking	Hag/peat bank reprofiling	Bunding	Forestry - tree removal	Scrub removal or management
2	Peat dams	Hag & gully reprofiling	Surface bund	Ditch and furrow blocking (forestry)	Mulch (scrub removal)
3	Wave dams	Gully reprofiling	Trench bund	Forest mulching	
4	Plastic piling dams	Ditch reprofiling	Cell bund	Ground smoothing	
5	Wooden/composite dams	Hag & gully blocking - peat dams/bunds		Stump flipping	
6	Stone/Rock dams (ditch blocking)	Hag & gully blocking - wooden dams		Ground smoothing, stump flipping	
7	Miscellaneous dams	Hag & gully blocking - geotextile logs or rolls		Ground compaction	
8	Ditch reprofiling	Hag & gully blocking - stone dams		Scrub removal (forestry)	
9	Grip blocking	Bare peat restoration		Mulch (forestry)	
10	Drain blocking	Eroded peat restoration		Brash removing/crushing	
11		Peat pan stabilisation			
12		Living mulch			
13		Seeding			
14		Fertiliser			
15		Sphagnum transplantation			

Note: Columns: broad categories A-E. Rows: Specific restoration activities (1-15).

7. Instead, we broadly categorise restoration activities and can use this information to assess variation in overall costs/ha depending on whether types of activities are present or absent. Note that this approach does therefore not distinguish costs/ha depending on extent of activities. It rather provides an idea of the types of activities and their distribution across applications in the PAP, and allows for a crude first approximation of how restoration costs/ha vary depending on activity.
8. Restoration activities were broadly categorised into five main categories, following Table 1. This categorisation approximately follows the latest revision of AF and FF forms. All activities not matching with the activities in Table 1 were summarised as "other" but are not analysed (29 AF and 15 FF of the 442 records analysed; and 31 AF and 16 FF in entire dataset).
9. Categories D (Forest to bog) and E (scrub removal) were aggregated for the analysis in this report.
10. See Figure 3 for the spatial distribution of restoration activities as recorded in FF.



The proportion of FFS sites per postcode area using each category of restoration activity (see text).
AB (Aberdeen), DD (Dundee), DG (Dumfries), EH (Edinburgh), FK (Falkirk), G (Glasgow), HS (Comhairle nan Eilean Siar), IV (Inverness), KA (Kilmarnock), KW (Kirkwall), KY (Kirkaldy), ML (Motherwell), PA (Paisley), PH (Perth), TD (Galashiels), ZE (Shetland). Produced in ArcGIS Pro.

Figure 3. Proportion of FFS (out of the total in each postcode area) carrying out each type of restoration activity.

Site designation and current use

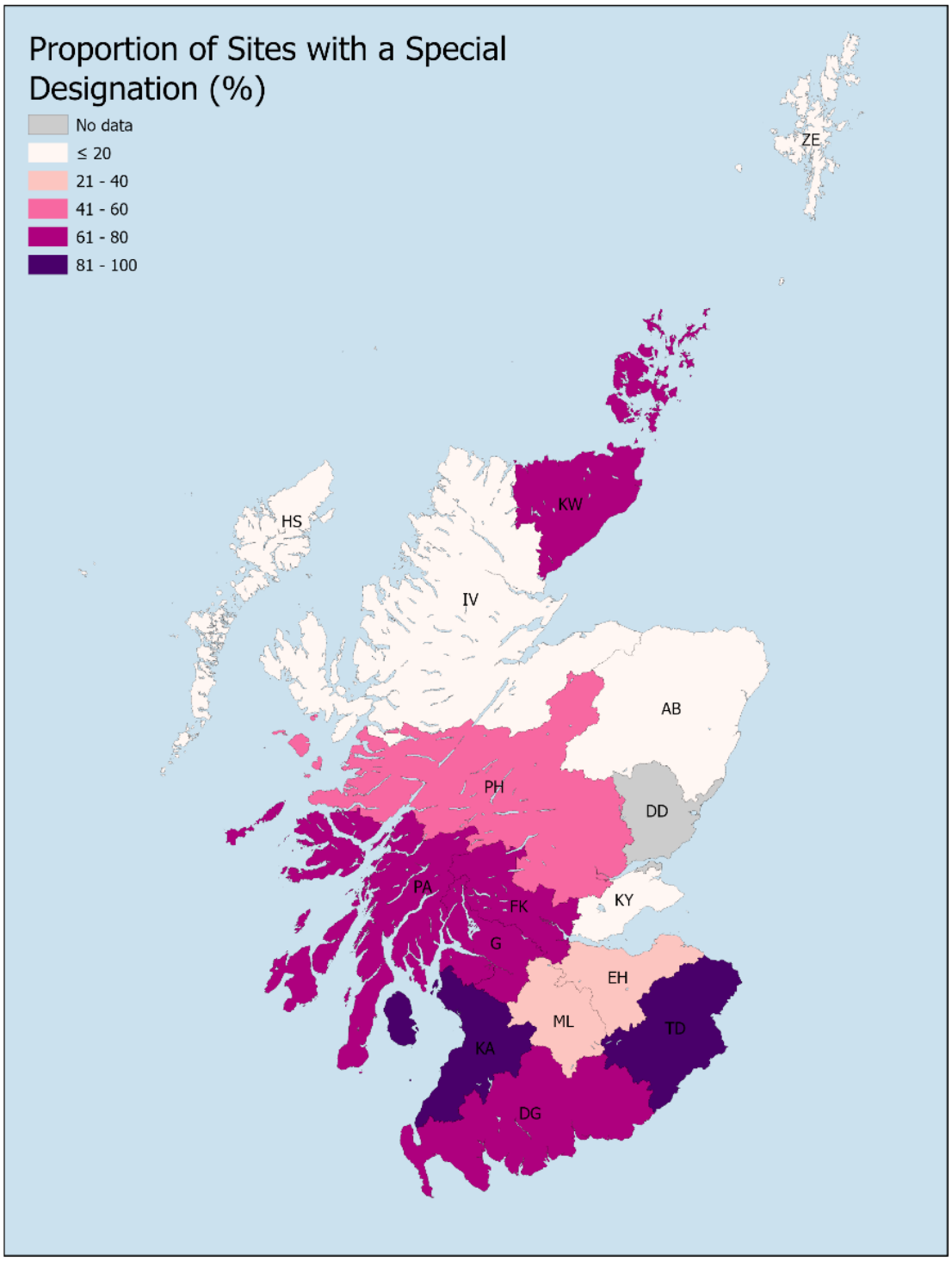
Table 2 presents a brief overview of site designations and current uses reported for 274 restoration sites. Designation and use information is missing for 26 unique restoration sites.

9. More than half of the sites (58%) have a site designation, with specific designations as shown in Table 2, and the distribution of designations shown in Figure 4.
10. In terms of current use of restoration sites, biodiversity conservation was reported by applicants and grantees in 39% of sites. In terms of productive use, deer management (49%) and rough grazing (41%) have considerable shares, followed by field sports and forestry (Table 2).

Table 2. Overview of site designations and current use of sites.

	Frequency	Percentage[a]
Designation		
No Designation	117	42.7
SSSI	54	19.71
SAC	23	8.39
SPA	31	11.31
NSA	31	11.31
NNR	45	16.42
Other (incl. National Park, Biosphere Reserve, LNR, Geopark)	65	23.72
Current Use		
Missing information	12	4.4
Rough grazing (sheep)	112	40.88
Forestry	37	13.50
Field Sports (grouse or rough shooting)	67	24.45
Deer management	133	48.54
Biodiversity conservation	107	39.05
Other	28	10.22

Note: [a] Percentage is relative to total number of 274 unique restoration sites, and more than one designation or use is possible on one site (i.e., percentages will not sum to 100 for Designation and Current Use).



The proportion of FFS per postcode area with a site designation (SSSI, SAC, SPA, NSA, NNR or Other).
AB (Aberdeen), DD (Dundee), DG (Dumfries), EH (Edinburgh), FK (Falkirk), G (Glasgow), HS (Comhairle nan Eilean Siar), IV (Inverness), KA (Kilmarnock), KW (Kirkwall), KY (Kirkaldy), ML (Motherwell), PA (Paisley), PH (Perth), TD (Galashiels), ZE (Shetland). Produced in ArcGIS Pro. Scale 1:2,750,000.

Figure 4. Proportion of FFS per postcode area with a site designation.

Descriptive analysis

This Section provides a descriptive overview of main features of the database, including an overview of costs/ha by application type, funding year, activity and site condition.

1. Table 3 reports area restored, associated costs and costs/ha by application year and whether data from AF or FF are considered. Figure 5 shows a histogram of Costs/ha for AF and FF data. Figure 6 shows the mean and median costs/ha by postcode area.
2. Results from Table 3, also discernible in Figure 1, show that there is a clear difference in cost per hectare between AF (estimated costs) and FF (realised costs): values for cost per hectare tend to be lower when based on FFS compared to AFS (an exception is application year 17/18). Across all AF, mean cost per hectare is £1896 (median: £1205). The estimate across all FF is £1712 (median: £1026). Among the FF, one outlier observation has a restoration cost exceeding £50k/ha. This explains partly the large difference between mean and median cost per hectare for FF, which is thus considerably lower once sites with very low and very high calculated cost per hectare are removed (FFS Truncated)**.**
3. It is apparent that there is significant variation in cost per hectare estimates for AF and FF: standard deviations are large and remain large even if particularly low or high values are excluded (truncated). Excluding very small and very large values, the mean for FFS is £1209 per hectare ith the median remaining £1026.
4. Both years 19/20 and 20/21 show a relatively small disparity between cost per hectare estimates for AF and FF. This may be an indication of learning among applicants and improved advice at planning stage.
5. Although it is too early to determine a clear time trend, mean costs per hectare appear to decrease from years 17/18 to 20/21. However, no trend can be discerned for median estimates. A future trend analysis would have to be mindful of comparing sites with similar circumstances across time.
6. Calculated values from AFS and FFS data cannot be compared directly because there is only partial overlap of sites. If cost/ha estimates are compared between AFS and FFS for the same restoration sites, the same pattern is observed: cost/ha is considerably larger for AFS. This can be due to several reasons, including i) overestimation of measures needed for restoration; ii) overestimation of restoration costs for specific measures; iii) changes in the area under restoration. Applicants received guidance on restoration from Peatland Action officers – this likely contributed to adjustments between initial proposals and actual implementation. Differences may also be due to challenges in implementation within a funding and reporting year, or with timely access to contractors or materials for restoration. It would thus be preferred to rely on data from FFS for policy guidance and cost-benefit analysis; nevertheless, data on AFS may still be used to investigate systematic variation in costs.

Table 3. Summary statistics (mean, median and standard deviation) of area restored (ha), overall costs (£) and costs/ha (£) by application year (16/17; 17/18; 18/19; 19/20; 20/21) and type of form (application form sites: AFS; final reporting form sites: FFS).

	Area (ha)			**Costs** (1k £)			**Costs/ ha** (£)			**N**
	Mean	Median	Std. Dev.	Mean	Median	Std. Dev.	Mean	Median	Std. Dev.	#
AFS 16/17	134.4	64.7	183.58	63.79	55.98	42.59	1870.73	1777.85	1602.09	4
FFS 16/17	88.9	–	–	80	–	–	899.89	–	–	1
AFS 17/18	63.94	33	123.92	60.19	39.04	67.16	1923.59	1185.86	2061.32	107
FFS 17/18	41.17	30	37.68	42.77	34.50	38.05	2393.37	999.68	7408.39	51
AFS 18/19	70.03	27.16	102.09	87.76	43.29	107.8	2207.2	1243.49	2365.42	83
FFS 18/19	67.27	27	102.78	62.88	23.34	98.4	1557.69	939.37	2653.21	59
AFS 19/20	55.07	35	62.5	65.88	38.17	76.97	1638.13	1403.9	1198.45	57
FFS 19/20	53.02	36.05	54.43	56.58	37.25	61.70	1434.97	1291.7	952.46	46
AFS 20/21	65.78	43	99.80	51.76	28.9	60.35	1077.42	1086.23	839.81	17
FFS 20/21	73.9	43	131.16	48.6	24.08	56.51	997.84	970.82	751.86	17
AFS Total	**65.11**	**31.85**	**105.80**	**69.46**	**39.02**	**83.69**	**1896.25**	**1204.63**	**1965.93**	**268**
FFS Total	**56.62**	**32**	**80.38**	**54.02**	**32.43**	**71.34**	**1711.71**	**1025.95**	**4327.83**	**174**
AFS Truncated[a]	**62.45**	**34**	**92.81**	**72.88**	**42.69**	**85.93**	**1656.2**	**1203.21**	**1284.08**	**241**
FFS Truncated[a]	**56.26**	**33**	**81.31**	**52.96**	**32.43**	**67.93**	**1209.08**	**1025.95**	**796.19**	**158**
FFS Trunc no IK	56.26	33	81.31	50.60	30.65	65.76	1163.14	949.55	796.44	158

Note: [a] Truncated: indicates values were included if <= 5th percentile or >= 95th percentile

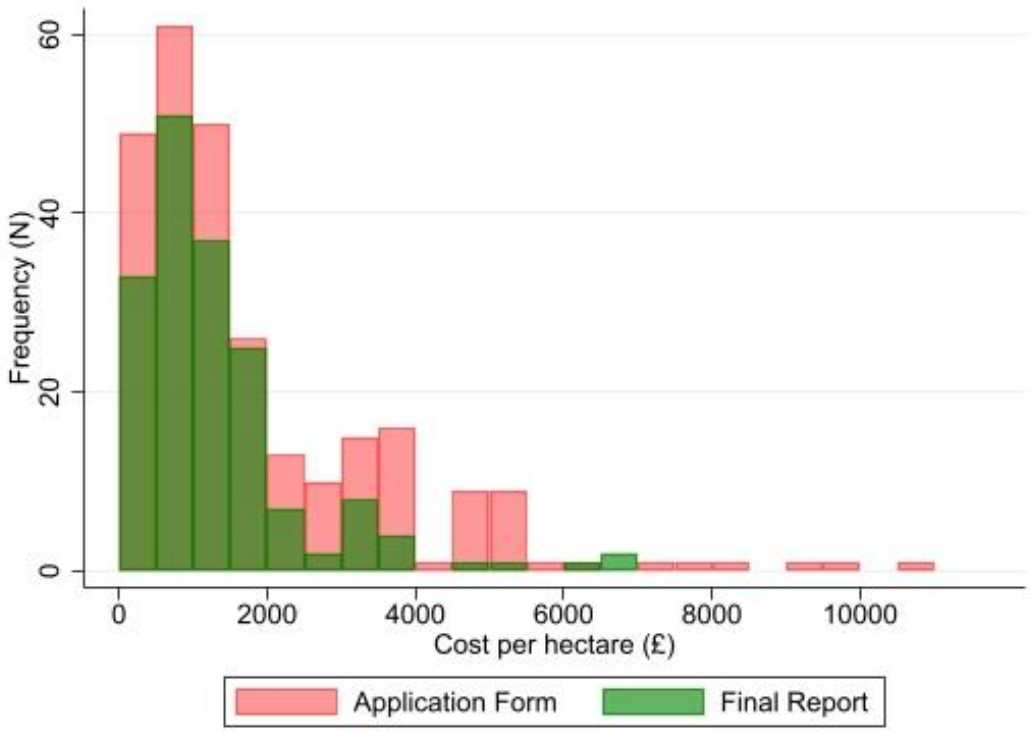
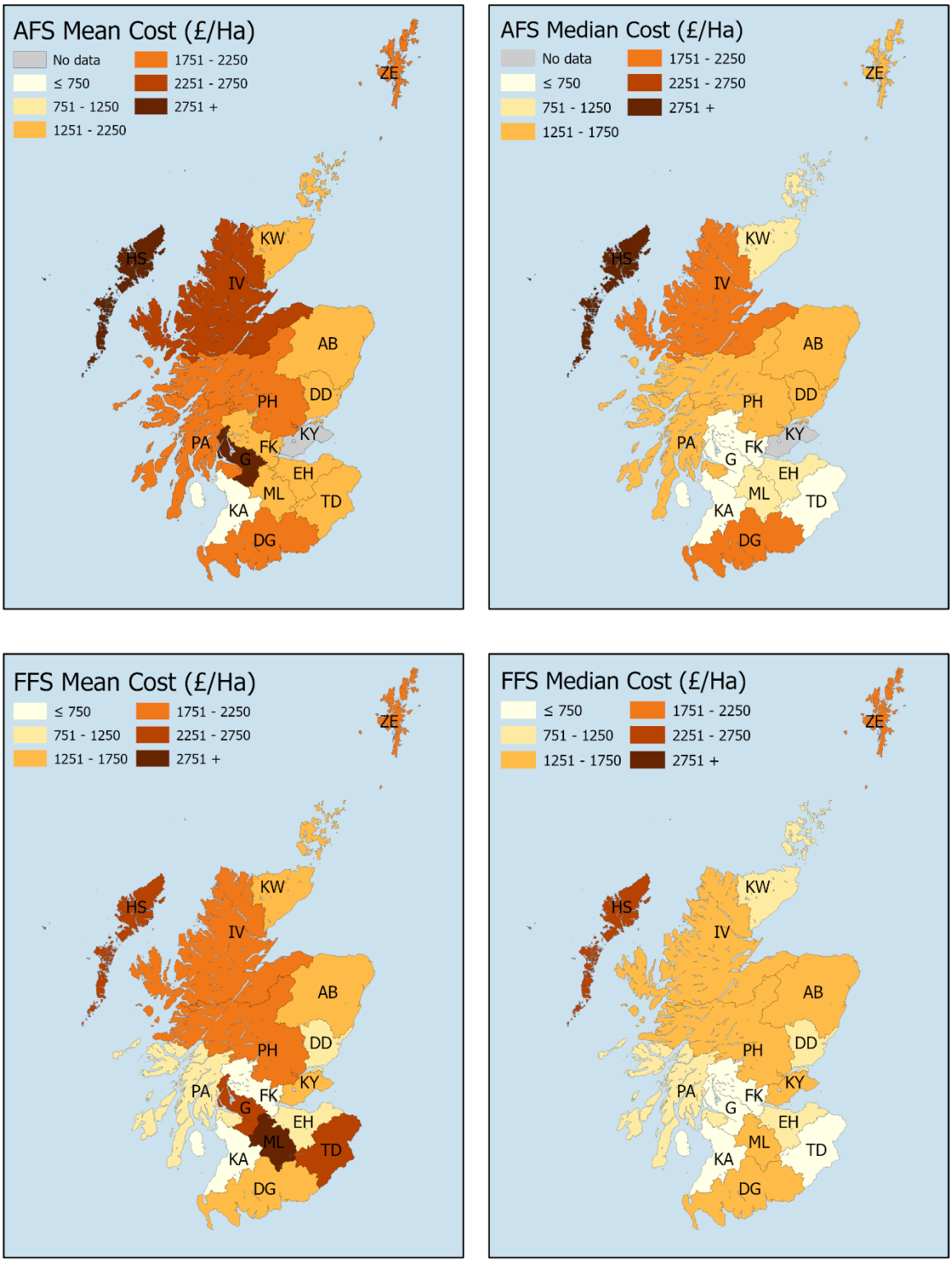


Figure 5. Histogram of costs/ha for records by type of form (Application form and Final reporting form). Three observations >£12k/hectare are omitted



The mean and median costs per hectare of AFS and FFS by postcode area.
AB (Aberdeen), DD (Dundee), DG (Dumfries), EH (Edinburgh), FK (Falkirk), G (Glasgow), HS (Comhairle nan Eilean Siar), IV (Inverness), KA (Kilmarnock), KW (Kirkwall), KY (Kirkaldy), ML (Motherwell), PA (Paisley), PH (Perth), TD (Galashiels), ZE (Shetland). Produced in ArcGIS Pro.

Figure 6. Mean and median cost per hectare for AFS and FFS per postcode area.

7. Table 4 summarizes the percentage of overall costs that are incurred as project management (PM) costs and in kind (IK) costs in cases where PM costs or IK costs are reported, or are greater than zero.

Table 4. Summary statistics of share of overall restoration costs related to PM and IK costs for sites (N) where PM or IK costs are reported in either application forms of sites (AFS) or final reporting forms of sites (FFS).

	Mean	**Median**	**Standard deviation**	**Min**	**Max**	**N**
PM (%) – AFS	9.07	6.89	8.76	0.37	74.36	185
PM (%) – FFS	10.16	7.28	11.74	0.63	71.48	86
IK (%) – AFS	6.06	3.15	8.33	0.07	60.09	204
IK (%) – FFS	8.31	6.45	7.72	0.17	49.22	107

Note: Total AFS: N=268; total FFS: N=174; AFS and FFS are not directly comparable since at least a subset relate to different applications and sites.

8. Because we are not always able to always clearly distinguish PM costs from restoration costs in cases where there was lumping in the forms, these statistics represent rather an upper bound. Given this, it may be preferred to use the median rather than the mean as an indicator. For PM costs, the median value is approximately 7% depending on the type of form (AF or FF). For IK costs, mean values for IK costs range between 6% and 8%, with median values between 3% and 6.5%.
9. It is worth noting that PM costs do not typically consider support offered via the Peatland Action officers, and may only sometimes cover, partially, aspects that may be subsumed under transaction costs for the PAP. At the same time, it may be questioned if some expenses, for example for mapping and peat depth surveys, should be counted as PM costs.
10. Table 5 provides a summary of (combinations of) restoration activities proposed or reported as undertaken in AF and FF, respectively, for all those AFS and FFS for which information on activities was available. The Table also lists summary statistics of costs/ha for the combinations of activities. Categorisation of activities follows Table 1.

Table 5. Summary of restoration costs/ha by type of restoration activities and type of form.

	Application Forms				**Final Reporting Forms**			
Activities[a]	**Cost/ha** (£)			**N**	**Cost/ha** (£)			**N**
	Mean	Median	Std. Dev.	#	Mean	Median	Std. Dev.	#
A	704.23	621.45	431.46	16	1478.77	999.68	1278.85	11
B	720.19	774.22	533.37	27	765.69	1030.13	364.29	7
C	2136.04	–	467.09	2	–	–	–	–
DE	3980.32	3773.25	2849.32	16	1647.75	1417.59	1139.94	35
A-B	1592.45	1105.14	1881.14	121	1192	794.15	1219.81	83
A-C	3393.24	1840.91	3355.14	7	1021.77	–	–	1
A-DE	2632.15	2686.88	2041.03	30	1444.92	1068.21	1479.06	14
B-C	2699.41	2523.39	1624.51	14	1164.42	903.78	1036.53	6
B-DE	3241.17	3474.95	1620.59	4	1028.39	1028.39	81.42	2
C-DE	2909.32	–	64.6038	2	–	–	–	–
DE absent	1546.61	1071.38	1811.13	187	1190.47	880.30	1171.08	108
DE present	3104.48	3194.84	2299.14	52	1567.78	1291.50	1213.63	51

Note: [a] A: Ditch (grip) blocking; B: Hag, gully & bare peat restoration; C: Bunding; DE: Forest to bog restoration & Scrub removal; AFS Total: N=239; FFS Total: N=159; Categorisation of activities as per Table 1.

11. The use of dams was allocated to category A: ditch (grip) blocking, even if dams are also often used in combination with B: Hag, gully and bare peat restoration. This may contribute to explaining the raised value for ditch blocking (A) in final forms relative to hag reprofiling and bare peat restoration (B). Cost/ha for the combination of both (A-B) are in between the values of A and B alone.

12. There is a clear difference between sites which involved forest-to-bog restoration and/or scrub removal (DE present) and those which did not (DE absent). Restoration cost/ha is approximately twice as high in the presence of forest-to-bog restoration relative to the absence of such activities. This confirms similar findings by Artz and McBride (2017), Artz et al. (2018) and Okumah et al. (2019).
13. Table 6 shows restoration costs/ha by site condition before restoration (as identified by applicants and grantees). Numbers of observations are low for many cells, especially in cases where several conditions have been selected by applicants/grantees. Restoration costs/ha on sites that are actively eroding and involve removal of scrub and forestry appear to be higher, although more information especially from final reporting forms are needed to be more confident about this trend and to allow a more reliable appraisal of how restoration costs vary across *ex-ante* site conditions.

Table 6. Summary of restoration costs/ha by site condition and type of form.

	Application Forms				**Final Reporting Forms**			
Condition[a]	**Cost/ha** (£)			**N**[a]	**Cost/ha** (£)			**N**[a]
	Mean	Median	Std. Dev.	#	Mean	Median	Std. Dev.	#
Near natural (NN)	–	–	–	–	–	–	–	–
Modified (MOD)	1115.88	950.00	1057.48	13	9728.76	534.94	21462.04	6
Drained (DR)	1558.72	1093.53	1512.79	98	1255.07	1014.11	1154.70	60
Forestry (FOR)	3003.92	3009.62	1830.95	26	4183.09	727.53	6995.56	7
Scrub (SC)	2560.31	2863.64	1301.74	7	1316.58	747.26	1162.90	6
Actively eroding (AE)	2164.44	1594.71	2232.99	64	1452.27	1053.78	1243.60	29
NN-MOD	90.94	–	–	1	153.32	153.32		1
MOD-DR	602.34	635.41	341.85	4	1291.70	1291.70	0.00	4
NN-DR-SC	1275.50	751.84	1547.68	5	344.27	–	124.00	2
NN-DR-AE	1575.20	976.85	1044.02	3	1403.44	1374.83	256.71	3
MOD-AE	7784.39	9434.33	3807.32	5	691.41	–	–	1
MOD-DR-SC	1361.90	945.60	1282.37	13	1080.10	888.12	822.42	11
MOD-DR-AE	654.36	–	861.76	2	511.43	–	–	1
DR-FOR	607.52	–	65.48	2	549.41	–	–	1
DR-SC	1012.39	850.82	430.25	4	761.26	–	1.07	2
DR-AE	902.28	676.00	785.68	14	1021.77	–	–	1

Note: [a] AFS Total: N= 261; FFS Total: N= 135

Updated statistical analysis of systematic variation in restoration costs

In this Section we will illustrate how the data may be used for an analysis of systematic variation in restoration costs. There may be alternatives to the (linear regression) approach used here, for example mixed models.

1. Here, we only use data from FFs, and focus on variation in restoration costs (dependent variable) resulting from different restoration activities implemented (independent or explanatory variables), as shown in Table 5.
2. If the database increases through the entry of additional forms, a more refined analysis may add further useful insights. This includes, for example, including time trends and spatial/geographical factors, or an analysis of variation in costs depending on (initial) peatland condition and use.
3. Given the skewed distribution of restoration costs/ha (see Figure 5), we take the natural logarithm of cost/ha, which then enters the regression. The natural log of Cost/ha is approximately normally distributed. This is therefore a log-linear or semi-log model.
4. All independent variables take the value of one if a restoration activity or combination thereof has been reported for a particular site, else zero (i.e., all independent variables are dummy variables).

In semi-log expressions, the coefficients of dummy variables can be interpreted as follows. The coefficient indicates, in percent terms (%), how much lower or higher restoration costs/ha are on average as a result of an activity (or a combination of activities) being present. The % value for a shift from not having a restoration action present (dummy variable =0) to having it present (dummy variable=1) at a particular site is the exponential of the coefficient for the dummy variable minus one (multiplied with 100 to arrive at a percentage).

5. Table 7 shows the results of the regression. Six observations (sites) were omitted from analysis following an outlier analysis using Cook's distance and a rule of thumb of an observation being likely an outlier if Cook's distance is greater than 4/N, where N is the number of observations in the full sample (N=159). Variance was estimated using the Huber-White robust alternate estimate of variance.

Table 7. Regression of the natural logarithm of restoration costs/ha for sites in final application forms on restoration activities present in sites.

Variable	Coefficient	Standard error	p-value
DITCHBLOCK	**0.468**	0.217	0.033
HAGBARE	0.191	0.252	0.45
FORSCRUB	**0.719**	0.205	0.001
DITCHBLOCK-HAGBARE	0.006	0.160	0.971
DITCHBLOCK-FORSCRUB	**0.585**	0.175	0.001
HAGBARE-BUNDING	0.137	0.173	0.431
Intercept	**6.463**	0.166	0.000

Note: Number of observations (FFS): 150; R-squared value: 0.14; significant coefficients (at 5% level) in bold; Abbreviations are as follows: DITCHBLOCK: Ditch (grip) blocking; HAGBARE: Hag, gully & bare peat restoration; BUNDING: Bunding; FORSCRUB: Forest to bog restoration & Scrub removal.

6. The value of R-squared is rather low, suggesting that approximately 14% of variance is explained by indicators of (combinations of) restoration activities alone.
7. Three of the coefficients are significantly different from zero at the 5% level. The value of the intercept (if all explanatory variables are zero) is £641. Effects of activities being present (dummy variable =1) are relative to this value, i.e., a negative coefficient for explanatory variables indicates that a (combination of) activities is on average associated with a decrease in restoration costs; *vice versa* for positive coefficients.
8. Ditch (grip) blocking (*DITCHBLOCK*), including use of a variety of dams, has a positive association with restoration costs. All else equal, the estimated proportional change in restoration costs/ha relative to £641 as a result of *DITCHBLOCK* is 60% [95% confidence interval: 4%; 145%]. In other words, the presence of ditch blocking activities (including dams) is associated with approximately a doubling of restoration costs estimated at the intercept.
9. Having forest to bog/scrub removal as the dominant activities (*FORSCRUB*) has a positive association with restoration costs. This is the case for *FORSCRUB* alone, or in combination with ditch (grip) blocking (*DITCHBLOCK*). All else equal, the estimated proportional change in restoration costs/ha relative to £641 as a result of FORSCRUB is 105% [95% confidence interval: 37%; 208%]. In other words, the presence of forestry and/or scrub removal activities among restoration activities of a site is associated with a doubling of restoration costs estimated at the intercept. With a proportional change in costs/ha of 79% [95% confidence interval: 27%; 154%], the respective estimate for the combination *FORSCRUB-DITCHBLOCK* is of slightly lower magnitude.
10. The presence hag, gully & bare peat restoration (*HAGBARE*) is on average associated with a positive but insignificant change in restoration costs/ha relative (i.e. the 95% confidence interval

includes zero). The proportional shift in cost/ha resulting from *HAGBARE* is 21% [95% confidence interval: -26%; 99%]. The effect of *HAGBARE* in combination with ditch blocking (*DITCHBLOCK*) is also insignificant.

11. The coefficient of ditch (grip) blocking (*DITCHBLOCK*) in combination with bunding (*DITCHBLOCK-BUND*) is positive but not significantly different from zero (mean proportional change relative to £641 is 15% [95% confidence interval: -19%; 62%]). The number of observations for bunding (on its own or in combinations) is low, thus preventing the conclusion that the presence of bunding if applied in combination with bare peat restoration increases restoration costs. More data is needed to confirm this.

Conclusion

Understanding costs of peatland restoration is very important to inform economic analysis to inform decisions on allocation of (public) budgets to restoration. Information on costs of peatland restoration remains patchy and fragmented, and often based on small sample size. This report presents an updated analysis of what represents, to the best of our knowledge, the largest existing database on peatland restoration costs in the UK (and possibly internationally). This unique database was built on data collected during the grant application and reporting process of the Peatland Action Programme in Scotland.

We find a mean estimate of restoration cost per hectare using data from reports of actually incurred costs of £1712 (median: £1026). Excluding very small and very large values, median costs per hectare remain at £1026, while the mean estimate decreases to £1209 per hectare. On average, project management costs, excluding support offered through Peatland Action and its officers, are estimated to account for 10% of total restoration costs, and in-kind contributions are valued at approximately 8% of total restoration costs.

Differentiating by type of restoration activity and initial peatland condition, there is considerable variance in restoration costs per hectare within each activity and condition. Nevertheless, some systematic variation can be glanced from results. The quantitative analysis can be expanded by taking into account peatland condition and site specific (spatial) characteristics as a basis of further investigations into the cost-effectiveness of peatland restoration efforts.

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Appendix A – Differences in sites with and without location data

1. 310 unique restoration site locations were identified from forms (located sites: 261 AFS and 177 FFS, with overlap). Some sites either did not provide a location or provided a non-valid location (unlocated sites: 14 AFS and 25 AFS). **There were differences between located and unlocated sites that must be borne in mind when viewing the maps in this document**. These contrasts differed for AFS and FFS.
2. Regarding AFS, located sites were generally larger (M=72.8 ha) than unlocated sites (M= 57.8 ha). They had a greater proportion of sites holding a designation (59% vs. 43%), and more unlocated than located sites reported their designation as 'other'. Unlocated sites reported more field sports, deer management and rough grazing than located sites, but less biodiversity conservation and forestry. Unlocated sites were more likely to be actively eroded than located sites, and located sites were more likely to be drained. For activity categories A, B and C, a similar proportion of located and unlocated sites reported them (differences of 3%-12%). Category DE actions were more common in located sites (40%) than unlocated sites (7%).
3. Regarding FFS, located sites were generally larger (M=63.1 ha) than unlocated sites (M=46.7). They had a much greater proportion of sites holding a designation (61% vs. 8%), and reported greater site use, especially for rough grazing and biodiversity conservation. Unlocated sites reported their condition as drained, actively eroding and bordering peatland, but never as near natural, modified, or with forestry or scrub, unlike located sites. Unlocated sites reported comparatively low levels of restoration activity and none reported bunding; they also saw much lower proportions of improvements in the water table, in biodiversity and overall.
4. The differences between located and unlocated sites might be partly artefactual, due to the small sample of unlocated sites. Unlocated sites may also be associated with forms with less information – because applicants/grantees were not motivated to provide accurate and comprehensive information, because they did not consider location or other information relevant or because, with a site in poor condition or with few (intended) restoration activities, they were less willing to report their precise location.