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Posted Date: 20 December 2023

doi: 10.20944/preprints202312.1580.v1

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Assessing Carbon Sequestration Rates from Conservation Management: Price and Potential for Multi-Habitat Nature-Based Carbon Sequestration in Dorset, UK

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Abstract: Carbon offsetting is currently a major tool in managing carbon emissions and the drive to Net-Zero. This study aims to identify the offsetting potential of existing conservation schemes, and whether carbon offsetting credits could potentially finance the continued management of the conservation activities. The results from Dorset, in the UK indicate that many existing conservation schemes in woodland, heathland and grasslands can not only enhance biodiversity but also capture significant amounts of carbon. We show that the cost per additional tonne of carbon sequestered as a result of conservation activities varies considerably between different conservation projects. On average, the cost of this offsetting is £80 per tonne CO_2e sequestered and ranging between £120 and £0 depending on the project and whether existing biodiversity grants would be available. However, this figure was based on adapting and refining existing conservation projects, and did not involve expensive factors such as purchase of land, which make the prices potentially unrealistic. While the costs identified are higher than many offsetting schemes at present, it could present a useful option for those wishing to localise their offsetting, and could be combined with biodiversity credits or other credit schemes to make the higher costs more attractive.

Keywords: climate change; carbon offsetting; carbon crediting; biodiversity; nature-based solutions

1. Introduction

1.1. Background

Despite considerable issues on the effectiveness and implementation of carbon offsetting, and its potential to weaken the focus on carbon emission reduction, carbon offsetting schemes are becoming increasingly popular (Fankhauser et al. 2021). Carbon offsetting schemes are designed to either remove CO_2 straight from the atmosphere or provide infrastructure that bring emission reductions over time to offset actions that produce emissions (Hyams and Fawcett 2013). As a result, an activity that has been offset no longer is considered to contribute to atmospheric greenhouse gas concentrations (Hyams and Fawcett 2013). Carbon credits are a therefore a financial mechanism to allow offsetting. Polluters can purchase credits which allow them to emit a certain volume of carbon which has been pre-offset (Singh 2009).

Despite the rise in anthropogenically produced carbon, nature still provides by far the dominant fluxes of carbon into and out of the atmosphere and oceans (Friedlingstein et al. 2020). Ultimately, enhancing and restoring nature can benefit atmospheric carbon levels by sequestering carbon as well as increasing biodiversity, while addressing societal challenges. This is sometimes referred to as a Nature-based Solutions (NbS) approach (Calliari et al. 2019; Seddon et al. 2021).

Sequestration varies between habitats; woodlands for example have a greater sequestration average compared to heathland (Alonso et al. 2012; Gregg et al. 2021). Furthermore, the overall quality of the habitat will influence its ability to sequester (Amaral-Rogers 2021); a 30-year-old mixed

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native broadleaved woodland has a flux range of -2.5 to -25.5 tCO_2e ha^{-1} yr^{-1}, averaging at -14.5 tCO_2e ha^{-1} yr^{-1} (Gregg et al. 2021). A habitat in pristine condition will sequester more carbon than if it was degraded (Amaral-Rogers 2021), so a woodland in good condition may sequester a value closer to the higher end of the flux range, and closer to the lower end if degraded. As such, traditional conservation management practices which aim to improve habitat quality and enhance biodiversity should also result in improved carbon sequestration in most habitat types.

Highly biodiverse, species rich habitats, such as a high-quality grassland community, may also show greater ecological resilience compared to species poor communities (Tilman and Downing 1994). This means they will have a stronger potential to support and promote biodiversity and ecosystem resilience, a component which is important in the face of climate extremes (Isbell et al. 2015; Buotte et al. 2019). In terms of carbon sequestration, these stronger, biodiverse habitats may provide a more consistent sequestration rate, compared to an ecologically poorer habitat that may degrade with ecological stress (Amaral-Rogers 2021). However, it should be noted that habitats with low biodiversity, such as a conifer plantation, have high sequestration rates (Liu et al. 2018; Anderson 2021). Yet the fact remains that the lack of ecological resilience makes the monoculture less resistant to change and more prone to collapse if environmental perturbations were high (Isbell et al. 2015). As a result, trade-offs may arise, especially if management measures proposed (i.e. to maximise carbon sequestration) encourage low biodiversity options, like afforestation with non-native monocultures (Seddon et al. 2020).

Traditional conservation, especially within the UK, has been based on managing a diverse range of habitats, often in different stages of ecological succession (Mitchell et al. 2000), with the focus being on protecting biodiversity as a whole, or a taxonomic group (e.g. birds) or even a particular species (e.g. Dartford Warbler) (Bibby, 1978). As such, a rich mosaic of landscapes and habitats exist. Despite this, conservation in the UK is considered underfunded, and overall biodiversity trends are poor (Burns et al. 2023). However, almost all habitats offer the potential to sequester carbon (Stafford et al. 2021), and the selling of carbon credits could provide a vital funding mechanism to finance conservation, resulting in reduced atmospheric carbon and enhanced biodiversity and more resilient habitats. With targets to conserve and protect 30% of land and sea by 2030 being adopted by many countries (Bailey, 2022), understanding the extent to which conservation measures for biodiversity can sequester carbon is also important. As such, the aim of this study is to obtain preliminary data on likely carbon sequestration of different conservation projects across different habitat types, and to calculate the cost of these conservation initiatives. As such, we can estimate necessary costs to sequester a tonne of CO_2e and see if a potentially viable mechanism exists to fund conservation projects. We focus the study in Dorset, in the south of the UK due to a wide range of conservation initiatives taking place in the region.

2. Materials and Methods

The study has been fully approved through the Bournemouth University ethics process.

2.1. Site Selection

A wide variety of sites, with different habitats and under different ownership models, were selected (Figure 1). The chosen sites include:

1. Rempstone Estate, Purbeck Heath – Private Estate (491.66ha).
2. Studland, Purbeck Heath – Nature Reserve (308.18ha).
3. Slepe Heath, Purbeck Heath – Nature Reserve (90.22ha).
4. Wild Woodbury, Bere Regis – An old farm now managed as a rewilding site (157.69ha).
5. Chapel Gate, Christchurch – University Sport Facility (23.05ha).

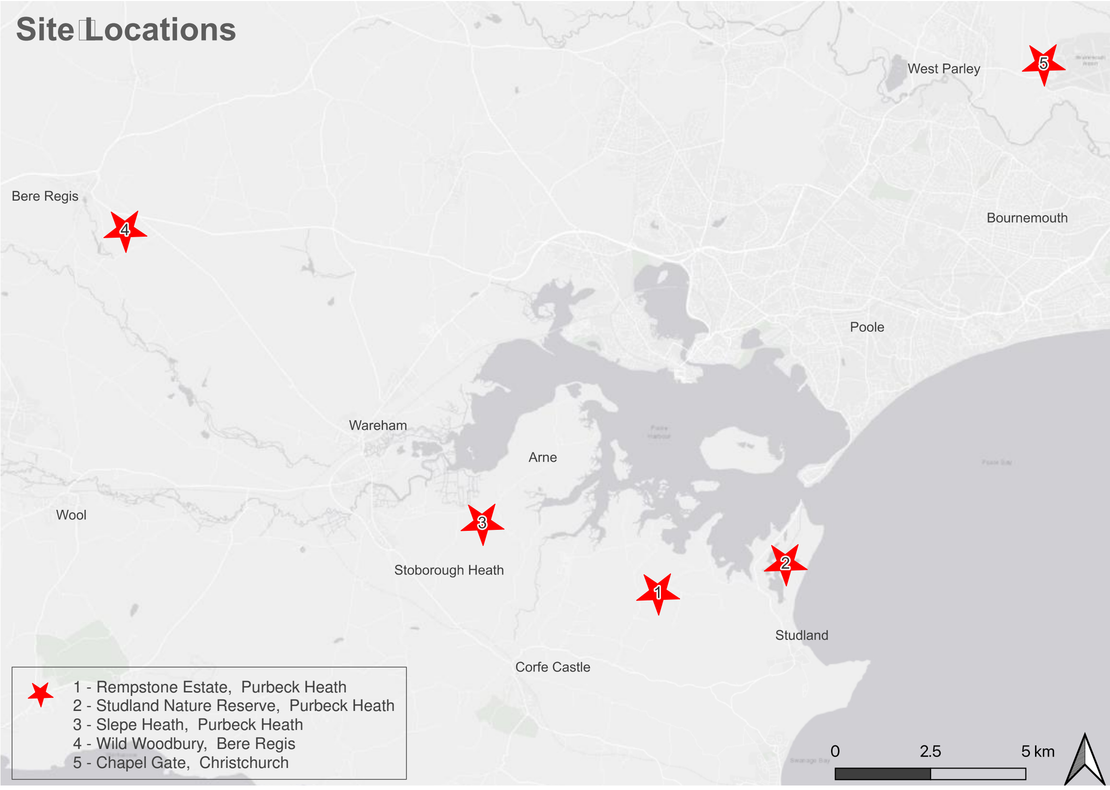

Figure 1. Locations of chosen sites situated across Dorset, UK. Scale 1:100,000.

2.2. Data Collection

After landowner permissions were obtained, site visits were conducted. Habitat surveys provided habitat types for each hectare of land across the five sites. Where available, the habitats were cross-referenced against data provided by the landowner.

CO_2e sequestration values were then categorised by habitat type (Table 1). Reports from Natural England (Alonso et al. 2012; Gregg et al. 2021) and the British Ecological Society (Stafford et al. 2021) provided the foundation for this, for a wide range of habitats, and the remaining was supplemented with other literature. Together, the datasets provided a comprehensive set of sequestration values required for our analysis.

2.3. Sequestration Calculations

Analysis was conducted using QGIS, an open-source geospatial software that enables the data to be examined in relation to its location. The National Trust provided data for their three sites, denoting extents and habitat information. For Chapel Gate and Wild Woodbury, sketch maps created during the site visits were digitized to create similar datasets to the other sites.

For all five sites, the area was calculated for each habitat polygon. Then each polygon was assigned an averaged CO_2e sequestration value based on its assigned habitat (Table 1). Using the area and sequestration rates, the annual sequestration was then calculated for each habitat polygon, for each site. Next, changes to improve sequestration rates were determined (i.e. planned or potential conservation work) and a new averaged CO_2e sequestration value was assigned to each polygon and the annual sequestration rate was then re-calculated. The average sequestration rate per hectare for each site was then calculated, for both before and after the changes suggested.

2.4. Cost Calculations

Cost calculations were based on the area of land within each site subject to changes in management and habitat (detailed in section 3.1), and did not include the entire area of the site. This

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meant sequestration measures did refer to changes in carbon sequestration (i.e. the management of the site resulted in additional carbon sequestration, and this additional carbon, not the existing background levels of carbon sequestration, was the only carbon used in the sequestration and cost calculations). Some long-term estimates of carbon sequestration and emission are uncertain, for example, how long deforested land will emit carbon (Gregg et al. 2021), as such we conservatively confine our calculations to sequestration taking place over five years (although we do discuss these implications on the cost of land).

Our cost calculations are based on the 'Base Rate', meaning just the costs involved in habitat creation (e.g. cost of saplings, seed, equipment hire) and maintenance of habitats over the five year period. In addition, we estimate labour costs of habitat creation and maintenance and land purchase costs (average land price in Dorset, UK, per Hectare, based on 2022 data), and also account for any government grants available to enhance biodiversity (see section 3.1 for details). Cost parameters are provided in Table 2.

Table 1. Carbon flux rates ordered by habitat, with confidence and source. Data collated from Natural England reports (Alonso et al. 2012; Gregg et al. 2021) and other sources (Anderson 2021; The Lake District National Park Authority ca. 2022). Negative values denote sequestration; positive values denote emissions.

Habitat	Sub-Habitat	Carbon Flux Rate (t CO_2e ha^{-1} yr^{-1}) [range]	Confidence	Source
Woodland*	30yr Mixed Native Broadleaved Woodland	-14.5 [-2.5 to -25.5]	Medium	Gregg et al. (2021)
	100yr Mixed Native Broadleaved Woodland	-7 [-2 to -13]	Medium	Gregg et al. (2021)
	30yr Oak Woodland	-15 [-1 to -18]	Unknown	Gregg et al. (2021)
	Conifer Plantation (Commercial Forest)	-12.5 [-5 to -20]	Low	Anderson (2021)
Scrub/Bracken	Scrub	0 – Soil only	Unknown	Gregg et al. (2021)
	Bracken	0 – Soil only	Unknown	Gregg et al. (2021)
Heathland**	Lowland Heath – Maintained: Burning, grazing, scrub clearance	-0.07	Low	Alonso et al. (2012)
	Lowland Heath – Restored: Scrub removed	+2.56	Low	Alonso et al. (2012)
	Lowland Heath – Restored: Trees removed	+4.46	Low	Alonso et al. (2012)
Semi-Natural Grassland***	Acid Grassland (*Molinia caerulea* swards: Low level grazing)	-0.5	Low	Gregg et al. (2021)
	Acid Grassland (*Molinia caerulea* swards: Ungrazed)	-0.53	Low	Gregg et al. (2021)
	Calcareous Grassland	-0.24	Low	The Lake District National Park Authority (ca. 2022)
	Neutral Grassland	0	Low	Gregg et al. (2021)
	Undisturbed semi-natural grassland under long-term management	0	Low	Gregg et al. (2021)
Farmland	Arable/Cultivated Land	+0.29	Low	Gregg et al. (2021)
	Improved Grassland	-0.36 [-1.28 to +0.92]	Low	Gregg et al. (2021)

Semi-Natural Peat Habitats	Fens on Deep Peat (Near Natural Fen)	-0.93	Medium	Gregg et al. (2021)
Floodplains	Floodplain	-3.365 [-2.13 to -4.19]	Low	Gregg et al. (2021)
Coastal	Sand Dunes	-2.18 [-2.13 to -2.68]	Low	Gregg et al. (2021)
	Salt Marsh	-5.19 [-2.35 to -8.04]	Low	Gregg et al. (2021)
Lake	Mesotrophic Lake	-7.1 [-0.46 to -23.6]	Low	Gregg et al. (2021)

* Sequestration rate after 10 years. ** 5-year average. *** There is limited evidence regarding carbon flux data for semi-natural grasslands in England, most notably, calcareous grasslands (Gregg et al. 2021).

Table 2. Cost parameters used in the cost calculations.

Parameter and units	Value
Time frame considered for offsetting (years)	5
Basic wage (£)	20
Skilled wage (£)	40
Cost of Trees (£/Ha)	649
Grassland seed (£/Ha)	189
Cost of land (£/Ha)	9000
Tree planting (number per hour)	12
Price of tree (£)	0.59
Tree density (per Ha)	1100
Grassland seeding (hours per hectare)	1
Cost of heathland creation (£/Ha)	370
Labour for heathland creation (hours per Ha)	50

3. Results

3.1. Proposed Conservation Measures

Below are the proposed conservation measures to be implemented at each site. Detailed maps of how sequestration is predicted to change between 2022 and 2032 are provided in supplementary material (Figure S1). Government grant information is correct as of August 2022.

3.1.1. Rempstone Estate Improvements

Rempstone Estate had notable planation cover until recently when parts of the plantation were cleared; this has led to those areas emitting carbon, which needs to be addressed if sequestration gains are to be achieved, although it should be noted that as the plantation was planted on shallow peat, net carbon flux was likely positive (emitting, rather than sequestering) prior to clearance. It is proposed that the 93.21 hectares of cleared conifer plantation is converted to heathland and maintain with burning, grazing and scrub clearance. This will stabilise the carbon stores in the soil (reducing the current 416 t $CO2e.yr^{-1}$ emissions) as well as sequestering a small amount of carbon through the heathland habitat (net sequestration by 2032 estimated as 6.52 t $CO2e.yr^{-1}$. Government grants (LH1) of £335/ha are available currently for this work.

3.1.2. Studland Improvements

Studland is a well-established biodiversity hotspot, and already has a good sequestration ability. Some changes could be made to enhance sequestration which would involve cutting back some of the larger patches of bracken and scrub and restoring to sand dune habitats (a total of ~10 ha). In total

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net sequestration would increase by 21.69 t $CO2e.yr^{-1}$ across the site. Government grants (CT1) of £299/ha are available currently for this work.

3.1.3. Slepe Heath Improvements

Slepe Heath also had notable planation cover until recently, with the cleared areas currently emitting carbon; this needs to be addressed to bring about sequestration benefits. It is proposed that the 27.1 hectares of cleared conifer plantation is converted to heathland and maintain with burning, grazing and scrub clearance. As for Rempstone, this will stabilise the carbon stores in the soil (reducing the current 121 t $CO2e.yr^{-1}$ emissions) as well as sequestering a small amount of carbon through the heathland habitat (net sequestration by 2032 estimated as 1.9 t $CO2e.yr^{-1}$. Government grants (LH2) of £214/ha are available currently for this work.

3.1.4. Wild Woodbury Improvements

Wild Woodbury, an old farm, has large areas of arable and cultivated land cover, as well as some poor-quality neutral grasslands. These land cover types have poor sequestration abilities, emitting carbon, and they also have very low biodiversity. Suggested changes include planting 15ha of oak woodland, natural regeneration of 95 ha of arable land to low input grassland and 0.68 ha of mixed native broadleaf trees. A Government grant (SW7) of £321/ha is available for the arable conversion.

3.1.5. Chapel Gate Improvements

Chapel Gate, being a sports facility, is predominantly managed grassland as it is required for sports fixtures. As such, enhancing sequestration is slightly more challenging, with small pockets of land (total ~1.3 ha) being repurposed as native broadleaf woodland being the main strategy here. Due to the purpose of the site, no grants are available for this work.

3.2. Overall changes in sequestration

The changes outlined above only demonstrate changes in carbon flux obtained as a result of specific management measures on parts of the site. Over the entire sites, the carbon flux did increase for each of the different sites investigated, with an average change across all sites of an additional 0.93 t $CO2e.yr^{-1}$ being sequestered (Figure 2).

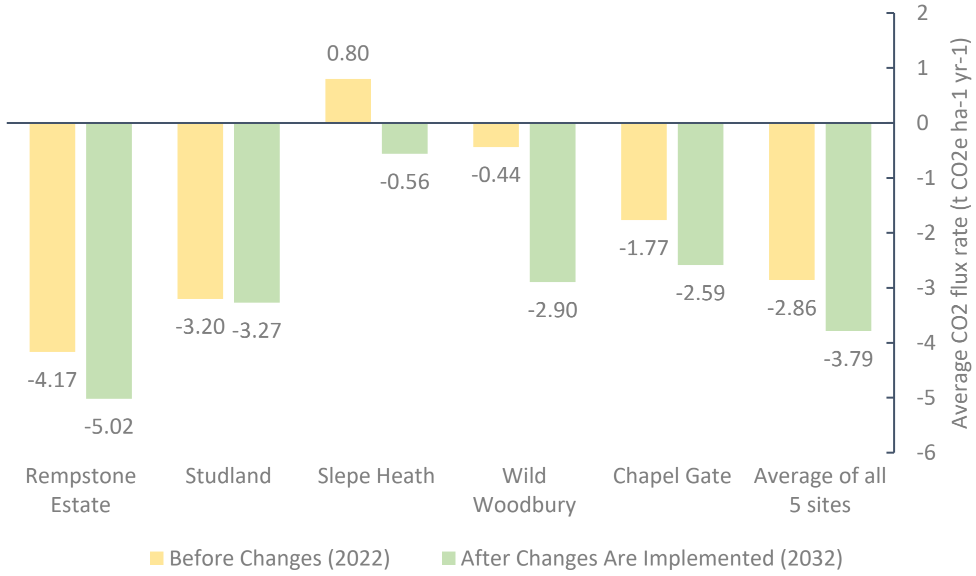

Figure 2. Carbon flux rate per hectare per year by site, both now (April 2022) and in ~10 years' time. Negative values (-) depict sequestration, and positive values (+) indicate emissions.

3.3. *Cost of conservation measures*

The costs of conservation measures range from base costs of ~£30 to ~£120 tCO_2e^{-1} (Table 3), with additional labour costs of between £3 and £100 tCO_2e^{-1}. The addition of land costs greatly increase the cost of a tonne of carbon dioxide equivalent, even with the inclusion of existing biodiversity grants. However, without land costs, the overall cost of some changes in conservation management, alongside government grants for biodiversity, can result in low, or even negative costs per tonne of carbon. Across all sites and interventions examined, the mean average cost of a tonne of carbon dioxide equivalent offset would be £79.62 without labour, £123.70 with labour, and £664.48 including purchasing land (based on five years of offsetting). Including government grants, the mean average is -£4.48 without labour, £39.59 with labour, and £580.38 including purchasing land.

Table 3. Calculation of costs associated with carbon offsetting based on the different conservation interventions proposed. Land cost and available grant are total values, based on the figures in Table 2 and section 3.1 multiplied by the total intervention area.

Site	Chapel Gate	Wild Woodberry	Wild Woodberry	Slepe Heath	Rempstone	Studland
Description of work	Plant/extend broadleaf woodland	Convert arable land to grassland	Plant/extend broadleaf woodland	Restore and maintain Heathland	Restore and maintain heathland	Sand dune conversion
Total Area	1.3	94.7	15.6	27.1	93.2	4.7
Total Sequestration of Intervention ($t.CO_2e.y^{-1}$)	18.95	123.45	233.77	122.76	422.21	10.34
Yearly maintenance cost proportion	0.1	0.1	0.1	0.2	0.2	0.1
Base cost of work (£)	590.59	12534.10	7077.99	12032.40	41385.24	1227.66
Base cost of work ($£.tCO_2e^{-1}$)	31.17	101.53	30.28	98.02	98.02	118.73
Hours of labour	131.1	94.7	1571.0	1626.0	5592.6	260.7
Cost of labour (£)	2621.67	1894.80	31419.67	32520.00	111852.00	5214.00
Cost of labour ($£.tCO_2e^{-1}$)	27.67	3.07	26.88	52.98	52.98	100.85
Land costs (£)	11700	852660	140220	243900	838890	42660
Land costs ($£.tCO_2e^{-1}$)	123.48	1381.39	119.96	397.36	397.38	825.15
Available Grants		30411.54		5799.40	31225.35	1417.26
Base cost of work with grants ($£.tCO_2e^{-1}$)	31.17	-144.82	30.28	50.77	24.06	-18.34

4. Discussion

In this study, we demonstrate the enhanced carbon sequestration which can be obtained from small changes in management to conservation sites. Sequestration applies across multiple habitats and is not restricted solely to tree planting. Our estimated costs of sequestration are typically higher than many cheap carbon offset schemes, but well within suggested ranges proposed by the UK government (BEIS 2021), even when including labour costs, but not when purchase of land is required. As such, carbon offsetting could be used as a mechanism to drive conservation funding in the UK, as long as the work is based on habitat creation and enhancement on existing land.

The sequestration rates found in this study can, on average, be considered modest when compared to typical tree planting schemes (across the entire site, ~ 1 t $CO2e.ha^{-1}.yr^{-1}$ compared to ~10 t $CO2e.ha^{-1}.yr^{-1}$ for a typical tree planting scheme). However, the sites used in this study do cover a

 doi:10.20944/preprints202312.1580.v1

range of habitats and uses of land, and illustrate how these habitats can be managed for biodiversity and carbon sequestration. While this is a small proof of concept study based in a single county in the UK, the 30 by 30 initiative to protect 30% of land by 2030 is an international effort (Bailey et al. 2022). If similar improvements to carbon sequestration were made to 30% of the Earth's landmass then an additional ~4.5 x 10^9 t CO2e.yr^{-1} would be sequestered, or a little over 10% of global emissions, based on 2021 data. Clearly, this figure is a very rough estimate, and is provided solely to show that additional carbon sequestration through well-managed conservation of what should be ear-marked protected sites can have a considerable impact on any drive to net-zero emissions and as such have global consequences in fighting the biodiversity and climate crises.

The main purpose of this study was to examine the market potential of carbon offsetting to finance conservation work. Averaged across the five sites studied, the costs, excluding labour, of creating or restoring habitats are ~£80 t $CO2e^{-1}$. Compared to many offsetting schemes, this cost is considerably higher (as of 12th September 2023, the top sponsored offset cost from a Google search was from Carbon Neutral Britain at £7.55 t $CO2e^{-1}$, or ~ 10 times lower). However, carbon offsetting has come under considerable criticism in the past year, with journalists and academics finding that most carbon credits sold fail to sequester any additional carbon (Greenfield, 2023; West et al., 2023). This is on top of additional concerns surrounding land grabbing for afforestation and neo-colonialist approaches to carbon offsetting in the global south (Navarro et al., 2023). While the values in this study are estimates, based on typical carbon sequestration rates per habitat, and would need quantitative verification before carbon credits were sold, they are based on additional gains in sequestration over the current base rates, and prices based on the cost of achieving these additional gains.

However, in terms of valuation of a tonne of carbon, the UK government suggest the value should lie between £126 and £378, with a typical value of £252 for 2023 values (BEIS, 2021). Our figures, including labour costs, fall well within this range, although as noted by Defra (2021), valuation and market price can and do show high degrees of discrepancy. While Rodemeier (2023) suggested a 'public willingness to pay' valuation, based on typical ecosystem service valuation methods, for carbon offsets of up to €200 per tonne, he suggests that these valuation mechanisms are flawed and a realistic market price at present is ~ €16 per tonne.

Within Global North countries such as the UK, where land prices are also excessively high, conservation-based carbon offsetting appears to be overly costly, without a multi-facetted approach to justify the high costs above market value. Currently, government grants under land stewardship schemes can be applied for which can greatly reduce the cost of conservation work which can also sequester carbon. Our estimates show that on average, these grants can fully cover the cost of any work, excluding labour costs, or with these grants, a tonne of carbon could cost ~£40 with paid labour. However, if carbon offsetting was routinely used for generating conservation funding, it is highly possible that grants such as these would be reduced or limited, given an additional funding mechanism had been put in place.

Conservation work has been shown to provide a wide range of benefits, well-beyond carbon capture alone. Through policy initiatives such as Biodiversity Net Gain (BNG) in England, but similar approaches in other regions of the UK and throughout Europe, markets for biodiversity credits are beginning to open, creating additional market mechanisms for conservation funding. Practical conservation work can also form a key part of a green workforce and Green New Deal strategies (Sokolnicki et al. 2022), yet many practical conservation skills are lacking in the general public, and even in graduates from degrees such as ecological or environmental sciences (Blickly et al. 2013). In addition, working on practical conservation in a volunteering role, has been shown to have physical and mental well-being benefits, often beyond those found from just being in nature (e.g. Kragh et al. 2016). Creating paid placement or apprenticeship places for students and trainees, as well as providing volunteering opportunities for conservation creates a low wage, yet high value workforce, considering the social, biodiversity and carbon benefits which can be created. As such, a credit system encompassing biodiversity, carbon and social benefits could be marketed, commanding a higher cost which would justify the full price (likely excluding additional land purchase) of the work. Such credit schemes may well be attractive to companies, especially if local to the conservation projects, as a measure of cooperate social responsibility and supporting local access to nature schemes.

Supplementary Information: Figures s1-10, Habitat maps and current and future sequestration rates of the study sites.

Funding: This research was funded by Bournemouth University.

Data Availability Statement: Data used from Natural England and The British Ecological Society is open source and can be found using the reference list. Data provided by the National Trust is not open source and can only be obtained with permission.

Acknowledgments: We would like to thank David Brown at the National Trust for his time and the data provided; Rob Farrington at Dorset Wildlife Trust for his knowledge, time and access to data resources; and Mark Rance from Bournemouth University's Chapel Gate site for his time and information.

Conflicts of Interest: The authors declare no conflict of interest.

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