Incentivising Biodiversity Net Gain with an Offset Market

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Abstract

Most programmes which incentivise the supply of public goods such as biodiversity conservation on private land in Europe are financed through the public purse. However, new ideas for how to fund biodiversity conservation are urgently needed, given recent reviews of the poor state of global biodiversity. In this paper, we investigate the use of private funding for biodiversity conservation through an offset market. The environmental objective is to increase some measure of biodiversity in a region ("net gain") despite the loss of land for new housing. Farmers create biodiversity credits by changing their land management, then sell these credits to housebuilders who are required to more-than offset the impacts of new house building on a specific indicator of biodiversity. Combining an economic model of market operation with an ecological model linking land management to bird populations, we examine the operation, costs and biodiversity impacts of such a (hypothetical) market as the target level of net gain is increased. A general result is established for the impacts on price and quantity in the offset market as the net gain target is make more ambitious. For a case study site in Scotland, we find that as the net gain target is increased, the number of offsets traded in equilibrium falls, as does the market clearing offset price. Changes in the spatial pattern of gains and losses in our biodiversity index also occur as the net gain target is raised.

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1. Introduction

Approximately 75% of global land has been "significantly altered" by human development, largely driven by land use change for infrastructure and agricultural production. These processes are predicted to continue, with nearly a million species thought to be at risk of extinction in the coming decades if no remedial action is taken (IPBES, 2019). While some call for over half the planet to be given over to biodiversity conservation (e.g. Dinerstein et al 2020), such an approach inevitably incurs significant economic and social costs. Indeed, halting land conversion and agricultural production to the extent required to address biodiversity losses may mean that it is impossible to meet a suite of UN Sustainability Development Goals (Nature, 2020; United Nations, 2018; IPBES, 2019). In place of restricting development completely, new approaches need to be applied that give governments, developers, regulators and wider society new tools to help reduce the negative impacts of development pressures on the natural world (Simmonds et al, 2020).

One such approach is biodiversity offsetting. Biodiversity offsetting aims to provide 'measurable conservation outcomes resulting from actions designed to compensate for significant residual adverse biodiversity impacts arising from project development' (BBOP 2009). To date, around 3,000 offset projects have been recorded worldwide covering at least 153,670 km^2, with the greatest number of compensation projects taking place in Brazil and Mexico (Bull and Strange, 2018). A widely accepted view is that "no net loss" should be the minimum standard for safeguarding biodiversity in the face of development impacts (Maron et al, 2020). More recently, countries are beginning to explore policies which focus on net gain or net positive impact on some indicator of biodiversity (Gibbons and Lindenmayer 2007; Maron et al. 2018). Net gain requires actions that ensure recreated or restored habitats exceed those lost in terms of potential biodiversity outcomes (that is, gains outweighing losses in some agreed metric) (CIEEM, CIRIA and IEMA, 2016). Net gain can be achieved in two ways 1) by over-compensating directly for the loss in biodiversity affected by development or 2) by first ensuring no net loss in the directly impacted biodiversity and then proving additional gains in other biodiversity values, known as "out of kind" compensation (Bull and Brownlie, 2017). Critical to both of these is the idea of additionality: only those actions that would have not otherwise occurred should be counted towards the creation of a biodiversity offset credit (Laitila et al 2014).

A number of questions arise when exploring the implementation of biodiversity net gain. Firstly, what should be the level of net gain delivered? This is an emerging debate within the ecological community at a global scale (see Maron et al 2020, Bull and Bronwlie, 2017 and Weissgerber et al 2019 for a detailed discussion). Maron et al (2020) argue that in countries where ecosystems are most severely depleted net gain is essential. However, in rare circumstances, a managed net loss should be allowed, where there is the greatest human development need and where natural ecosystems remain extensive (Maron et al 2020). A second question is who will deliver the net gain in biodiversity and at what economic cost? Within the context of housing and infrastructure development, a shift from a no net loss of biodiversity to some level of net gain creates additional demand for schemes which restore and recreate habitats to mitigate development impacts. One option to meet this increased demand is through a market for biodiversity offsets. Markets are created when multiple buyers and sellers of biodiversity offsets interact with others through a trading process. This creates a setting in which landowners can choose to manage land for conservation and generate offset credits. These credits can then be sold to a developer who is required to mitigate development impacts on some specific biodiversity metric. Such trades can be facilitated by an offset bank which collects offers from sellers and makes these available to potential buyers. Buyers will not offer more for a credit than the value to them of land for development, and sellers will require no less in payment than the opportunity costs of creating offsets (Needham et al, 2019).

There is an expectation that a change in the policy agenda from no net loss to a net gain will affect the demand for offsets and consequently will impact the functioning of a market for biodiversity offsets. Impacts include those on the prices at which credits are sold, the cost to developers, the gains to landowners who supply credits, and the resulting ecological landscape. This paper contributes to the literature by examining the economic and ecological impacts of increasing net gain requirements on a market for biodiversity offsets. We are not aware of any papers which have done this before. Using an integrated ecological-economic modelling approach, we examine the following important questions:

1. How does the equilibrium market-clearing price and quantity of offsets vary according to an increasing requirement for biodiversity net gain?
2. What is the effect on housing developers of a move from no net loss to net gain?
3. What are the ecological impacts of having no offset policy compared to various net gain scenarios, and how do these impacts vary spatially?

To answer these questions, we first develop a conceptual model of a biodiversity offset market, which compares the demand for offsets under (i) a policy target of no net loss with (ii) a policy target of biodiversity net gain. We then develop an empirical application of this conceptual model, which includes spatially-explicit biodiversity offset supply and demand curves under a range of no net loss and net gain policies. These supply and demand curves capture the spatial variations in the costs of supplying biodiversity offsets (which depend on the relative value of land for agriculture) and the demand for offsets, which depend on the value of new housing developments across the landscape and the net gain requirement.

We explore this in the context of the UK, as it is the first country in Europe to adopt legislation requiring a net gain in biodiversity for new development projects (infrastructure and housing) (HM Government 2018). It is estimated that the restoration of UK priority habitats will cost an annual average of £97 million per year (Raymont 2019). Whilst some of this can be delivered through the new Environmental Landscape Management scheme[2] -and thus be funded directly by the UK taxpayer - longer-term land management measures including habitat restoration and creation will require a different incentive structure than current agri-environment contracts (which typically last 5 years).

The remainder of the paper is organised as follows: Section 2 develops our conceptual model of biodiversity net gain, Section 3 provides information on the methods used including the integrated ecological-economic model and the case study region, Section 4 provides the results and Section 5 the discussion and conclusions.

2. Modelling the Biodiversity Offset Market

2.1. General Structure

We consider a region where land can be divided into three possible uses, which are mutually exclusive at any point in time: agriculture, development for new housing, and biodiversity conservation. We assume the land is currently owned and managed by farmers, while there are developers who wish to acquire land for housing development. We further assume that both farmers and developers are price-takers in their respective output markets as well as the market for offsets, i.e., no individual in either group has market power in either the offset market or the housing market.

In the first instance, for a land parcel to be developed, the developer must hold the relevant quantity of offsets, q, to satisfy a no net loss of biodiversity policy, that is the developer must buy one offset if it wants to develop one parcel of land. This requirement generates a demand for offsets credits from developers, $D(q)$. Ranking parcels of land that could be developed according to their expected housing value from highest to lowest yields a downward sloping demand curve for offsets. Here we assume that heterogeneity in reservation prices stems from differences in housing development rents (or house prices) across the landscape. Due to our assumption that the housing market is competitive, the reservation price for an offset that will allow development of a particular land parcel equals the net profit available from developing that land parcel. In equilibrium, each developer will choose to buy a quantity of offsets that equates their individual demand curve with the market price of offsets.

Offsets are supplied by farmers who choose to convert their existing agricultural land to conservation, which benefits biodiversity and thus generates a supply of offset credits, $S(q)$. We assume that for a

[2] The move towards net gain sits alongside a broader shift in UK agricultural policy. A new Environmental Land Management scheme will replace schemes available to farmers under the EU's Common Agricultural Policy, as Britain leaves the EU. The Environmental Landscape Management scheme will reward farmers and land managers with public money for the provision of public goods, including improvements in biodiversity, cleaner air and water, healthier soils, and natural hazard protection (Defra 2020).

farmer to supply offset credits, they must be compensated at minimum by the offset market for his opportunity costs of the foregone agricultural profits plus any associated restoration costs. Across the landscape, agricultural profits per land parcel may vary due to variations in agricultural productivity. This allows us to rank all agricultural land as a continuous, upward-sloping supply (or marginal cost) curve describing how many new offsets will be created for a given price, p. Each farmer maximises profits by choosing to supply the quantity of offsets that equates the marginal cost of creating new conservation areas (i.e., lost agricultural profit at the margin) with the offset price, p.

2.2. From No Net Loss to Net Gain

To keep the model transparent, assume that when the offset market operates under a no net loss biodiversity objective, the developer must buy one offset if it wants to develop one parcel of land – implying that all land is of equal conservation value (this assumption is relaxed in our empirical model). Given the aggregate demand and supply function introduced previously, the offset market will be in equilibrium when $D(q) = S(q)$, generating an equilibrium quantity of offsets, q^*, and equilibrium market price, p^* (see Figure 1).

A no net loss policy has the objective of preventing any decrease in some specified biodiversity metric as a result of development. Taking the no net loss policy as our baseline, we want to assess the configuration of the offset market if instead, a net-gain policy objective was to be imposed, where "net gain" means the policy target changes to one of achieving a specified *increase* in the biodiversity metric as a result of development. Changing from a no net loss to a net gain requirement does not affect the agricultural productivity of the land parcels, nor their potential ecological value, and hence does not directly affect the costs to the farmer supplying offset credits. For this reason, changing the net gain target implies no shifting of the offset supply curve. In contrast, as we show below, changing the net gain target has an effect on the demand curve for offsets.

Under a net gain policy objective, a developer needs to purchase a quantity of offsets equal to $(1 + \theta)$, where θ is the percentage net gain that is required. To fix ideas, let us consider a given position on the demand curve $\left(q, D(q)\right)$ under the no net loss policy. For any such point on the demand curve, under a net gain policy, each development now needs to be offset by $q(1 + \theta)$ and the developer's reservation price for each offset decreases from $D(q)$ to $D(q)/(1 + \theta)$. Thus, relative to the baseline, the changes in the quantity demanded and corresponding reservation price for each offset can be represented by $\left(q(1 + \theta), \frac{D(q)}{(1+\theta)}\right)$. Re-organizing to express this new demand curve just in terms of a generic quantity of offsets q, we find that moving to a net gain policy shifts the original demand curve derived under the baseline policy to the new demand curve described by (see Figure 1):

$$\hat{D}(q) = \frac{D\left(\frac{q}{1+\theta}\right)}{1+\theta}. \quad (1)$$

Since the original supply function is unchanged, the new market equilibrium under a net gain policy entails the equilibrium quantity and price combination $(\hat{q}, \hat{p})$ that solves (see Figure 1):

$$\hat{D}(\hat{q}) = S(\hat{q}). \quad (2)$$

As the net gain parameter θ is varied, the equilibrium price-quantity combination will vary, so $(\hat{q}, \hat{p}) = (\hat{q}(\theta), \hat{p}(\theta))$.

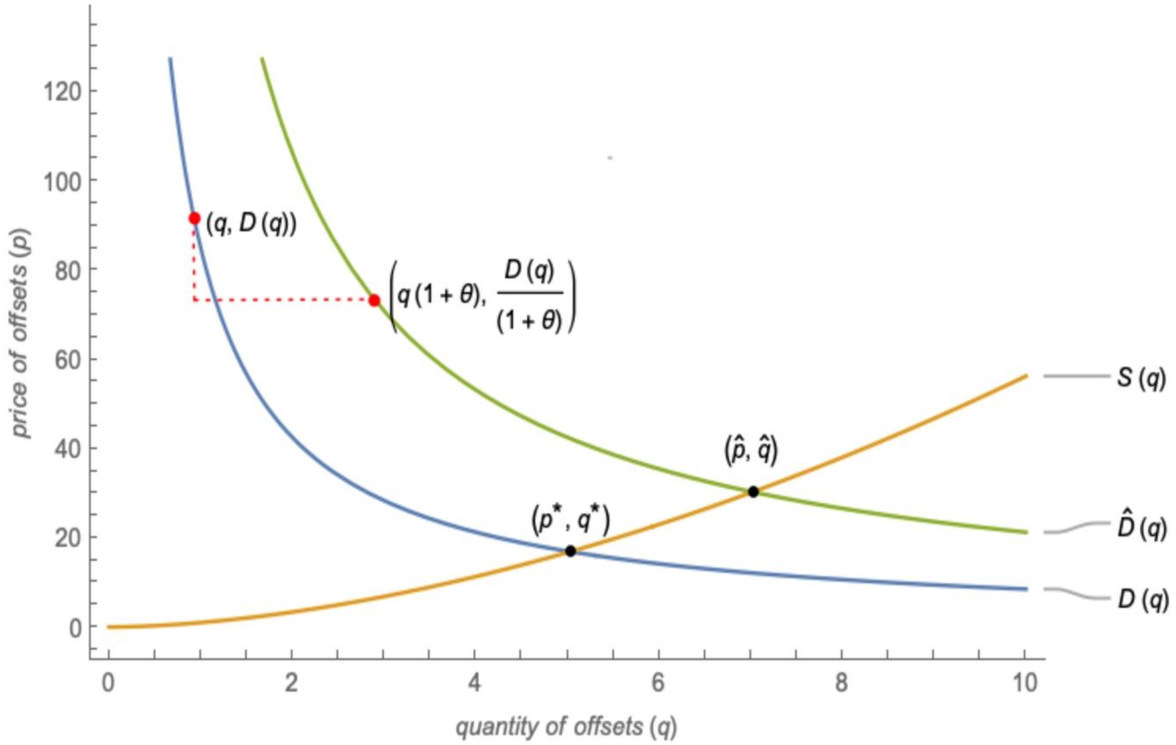

Figure 1: Demand shift from no net loss to net gain policy and equilibrium price-quantities

This brings us to a point that allows us to determine how the market equilibrium price and quantity of offsets is affected by an increasing biodiversity net-gain requirement. Applying implicit differentiation of (2) and substituting into (1), we can recover the effect of increasing the net gain requirement θ on the equilibrium quantity of offsets (see Appendix for derivation):

$$\frac{\partial \hat{q}}{\partial \theta} = \frac{\frac{\hat{q}}{1+\theta} D'\left(\frac{\hat{q}}{1+\theta}\right) + D\left(\frac{\hat{q}}{1+\theta}\right)}{D'\left(\frac{\hat{q}}{1+\theta}\right) - S'(\hat{q})(1+\theta)^2} \gtrless 0. \quad (3)$$

The general expression in (3) indicates that the effect of an increase in the net gain requirement is ambiguous and depends on the sign of the numerator (noting that D' is negative and the denominator is negative). However, by focusing on a small change from the market equilibrium in no net loss baseline case, i.e., a small movement towards a net gain policy, we can evaluate the effect of a marginal increase of θ more accurately. That is, evaluating (3) at $(q(\theta), \theta) = (q^*, 0)$ yields (see Appendix for derivation and proof):

(4) $$\left.\frac{\partial q}{\partial \theta}\right|_{(q^*,0)} \gtreqless 0 \Leftrightarrow \epsilon \lesseqgtr 1,$$

where $\epsilon = \frac{\partial q/q}{\partial p/p}$ is the price elasticity of demand for offsets. Thus, (4) indicates that the change in demand for offsets due to a marginal increase in the net-gain requirement is solely determined by the price elasticity of demand at the no net loss equilibrium. The following proposition summarizes our key finding:

Proposition 1. *In competitive markets for biodiversity offsets and development, a biodiversity net-gain policy initially increases (decreases) the equilibrium quantity and equilibrium offset price if offset demand at the no net loss equilibrium is inelastic (elastic).*

As reflected in expression (3), our main theoretical result in Proposition 1 suggests that the effect of an increasing net gain requirement θ on the equilibrium quantity (and price) of offsets is ambiguous, but it allows us to predict the direction of change more precisely depending on the elasticity of demand at the original no net loss baseline policy. To put this main finding in perspective, we can compare this result with the extreme cases of perfectly inelastic ($\epsilon = 0$) and perfectly elastic ($\epsilon = \infty$) offset demand. When $\epsilon = \infty$ (the demand curve is horizontal) developers face the same rent (profit) value from development everywhere, meaning the demand curve is a horizontal line. When imposing a net-gain requirement in this case, each developers' reservation price for an offset decreases uniformly, leading to a lower price and quantity of offsets demanded in equilibrium. In contrast, $\epsilon = 0$ (the demand curve is vertical) implies an infinitely valuable development requiring a given number of offsets under a no net loss policy. Increasing the policy requirement to one of net-gain per unit of development would just shift that demand curve to the right, leading to an increase of the equilibrium price and quantity.

In the following section we develop an empirical version of the above model and use this to test the theoretical prediction summarized in Proposition 1.

3. The empirical approach

For our empirical example, we employ an integrated ecological-economic modelling approach first developed in Needham et al. (2020)[3]. The model seeks to maximise each landowner's joint profit derived from agriculture and new housing development within a region, subject to a regulatory limit of no net loss or net gain of a single ecological policy target. As a baseline, we take the current land use structure in the case study area which is of a fixed size. This area is divided into a number of $i = 1, \dots, n$ land parcels equalling a size of 100 ha and aligned to the Ordnance Survey British National Grid. Each land parcel is assumed to be managed by a single landowner. Each land parcel can comprise of any combination of 30 distinguished land use types including agricultural and crop classifications based on the Land Cover and Land Cover Plus Crops Map (Rowland et al. 2015).

Our model focusses on a single hypothetical policy target: the Northern lapwing (*Vanellus vanellus).* Lapwing appears on the Red-List (species in most urgent need of conservation action) of threatened bird species in the UK (Eaton et al 2015). Lapwing populations have declined by 54% in the past 50 years, partly due to changing farmland management. We use statistical regression on observed lapwing numbers across UK farmland to describe the relationship between the current land use and the current abundance of birds within a land parcel (Needham et al. 2020). Our estimate of current lapwing abundace represents the baseline no net loss conservation objective. For the net gain scenarios, the net gain objective is calculated on a parcel by parcel basis, with the baseline abundance simply multiplied by the net gain policy objective. For example, an offset for a parcel with a current abundance of two lapwing, would require habitat improvements elsewhere that would support four additional lapwings to be purchased under the 50% net gain scenario.

Lapwing numbers can be increased on land parcels by farmers replacing the current land use on a parcel with an ecologically-preferred land management practice, which enables offsets to be generated. We specify this conservation land management practice as improved grassland without livestock grazing. Grassland is more beneficial to lapwing population abundance than the alternative agricultural practices of crop and/or livestock production (Needham et al. 2020). To ensure additionality, this change in land management practice in the model can only take place on agricultural land patches currently farmed for crops or livestock. Our model assumes that contracting terms involved in generating offsets are such that the conversion of agricultural land to offset provision will be permanent, that is a farmer cannot switch between agricultural production and offset provision on a given land parcel.

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[3] Needham at al look at a no net loss target for three different ecological indicators.

In contrast to the theoretical model of Section 2, each land parcel is heterogeneous in ecological terms, implying that different land parcels can generate more lapwings, equating to a greater number of offsets generated, from a switch from current cropping to the conservation land management practice. Hence, higher ecological potential land parcels generate more valuable offsets when the land management conversion is undertaken than land parcels with lower ecological potential (lower ability to “produce” additional lapwings).

We assume that on all agricultural land parcels, the current crop and livestock distribution is at present the most profitable to a farmer; and that switching to an alternative land management practice will result in a loss of profit, incurring an opportunity cost. For each land parcel we generate the farmer’s minimum willingness to accept (WTA) a change from current agricultural land use to the conservation land use (grassland with no grazing). This gives us the minimum unit price at which a farmer would be willing to supply one offset:

$$(5) \quad WTA_i = \frac{\pi_i^1 - \pi_i^2}{\Delta b_i} \qquad (i = 1, \ldots, n)$$

where, π_i^1 is the gross margin of the land parcel under the current agricultural land use, π_i^2 is the gross margin of the land parcel under the proposed land management practice (grassland) and $\Delta b_i = b_i^2 - b_i^1$ denotes the increase in the lapwing (b) abundance gained from the binary decision to shift all agricultural land within a parcel to grassland.

Knowing the farmers’ WTA, land parcels can now be ranked according to the offset value they offer in terms of increased lapwing abundance, recovering the analogous supply curve to that shown in Figure 1.

Let us next consider what shapes the demand side of the market. A developer’s demand for offsets is determined by the expected value of the land for new housing development and the requirement to purchase offsets to satisfy the no net loss or net gain policy criteria. For each land parcel, we generate the developers’ maximum willingness to pay for a single offset:

$$(6) \quad WTP_i = \frac{r_i - \pi_i^1}{(b_i^1 + \theta)} \qquad (i = 1, \ldots, n$$

where, r_i is land rental value of the parcel for housing developement, $\pi_i^1$is the agricultural gross margin of the land parcel under the current land use, $b_i^1$is the abundance of lapwings currently supported by the land parcel and θ is the percentage net gain required under the no net loss or net gain policy.

Knowing the developers' maximum WTP for offsets, each land parcel can now be ranked according to its development value. This reveals which land parcels deliver the most offset profitable housing developments taking into account the offset requirements, and allows us to recover the analogous demand curve for offsets to that shown in Figure 1.

Having recovered the empirical supply and demand curves for offsets, we are now in a position to determine the price for a single offset at market equilibrium (p^*). At the market equilibrium price, we then determine whether a land parcel remains under current land use, becomes an offset supplier or is developed for housing. In particular, at each price point the farmer managing site i, will supply offsets if the market offset price $p^* \geq WTA_i$. In the same vein, at each price point, a developer will buy and develop parcel *i* and purchase offsets to compensate for the loss of lapwing if $p^* \leq WTP_i$.

We examine seven scenarios using our empirical model. Our aim is to compare the market clearing price for offset credits, the costs to developers of purchasing offsets, and the subsequent economic and ecological impacts market under different levels of net gain and no net loss, compared to the case where no requirement to offset is imposed at all.

- Scenario 1: *Full development on all profitable land parcels with no offsetting.* Under this scenario, all land parcels within the case study area that have a positive value for housing development are developed. This is the most "extreme" level of development with no planning regulations imposed, including no regulations on biodiversity loss. This would represent the greatest loss in the ecological policy target (the biggest decline in lapwings).
- Scenario 2: *No Net Loss:* Under this scenario, land parcels can be developed as long as the landowner holds an equal number of offset credits to the number of lapwings being lost. In this case, the net change in lapwings across the region as a result of new housing development should be zero. That is, local losses in lapwings are exactly balanced by gains elsewhere in the region.
- Scenarios 3 – 8: *Biodiversity Net Gain of* θ *= 5%, 10%, 20%, 30%, 40% or 50%.* Housing development can only occur so long as sufficient credits are supplied and purchased to increase the lapwing population across the region by the given level of net gain.

Comparing Scenario 1 with Scenarios 2-8 allows us to explore the ecological impacts of unregulated development compared to different levels of net gain. We can also explore spatially how ecological impacts change across the landscape under different scenarios. Comparing Scenarios 2 through to 8 allows us to examine the effects of increasing levels of net gain on the market clearing price for biodiversity offsets, and on the economic cost to developers of increasing net gain requirements.

A full account of all data sources used, and how these were processed for use in the model, can be found in the Supplementary Information.

Case Study

We apply our modelling approach to the Forth Valley, central Scotland, UK (Figure 2)[4]. The Forth Valley contains a mosaic of biodiversity-rich habitats from wetlands, marshlands and heather uplands, some of which are protected through the EU Habitats and Wildlife Birds Directive (92/43/EEC and 2009/147/EC). Biodiversity rich areas outwith these designations face pressure from the growing population within the central belt region for new housing (the case study area covers the cities of Edinburgh and Stirling), as well as further expansion of the heavy industry, ports and petrochemical complex of Grangemouth and Rosyth. As such this provides an ideal example in which to test our market for biodiversity offsets and net gain. Whilst the current UK net gain policy is being pursued by DEFRA through the central UK Government, the Scottish Government have committed themselves to similar policy frameworks through their Environment and Biodiversity Strategies, overseen by the regulatory and advisory bodies SEPA and Scottish Natural Heritage, (Scottish Government, 2020; Scottish Natural Heritage, 2019).

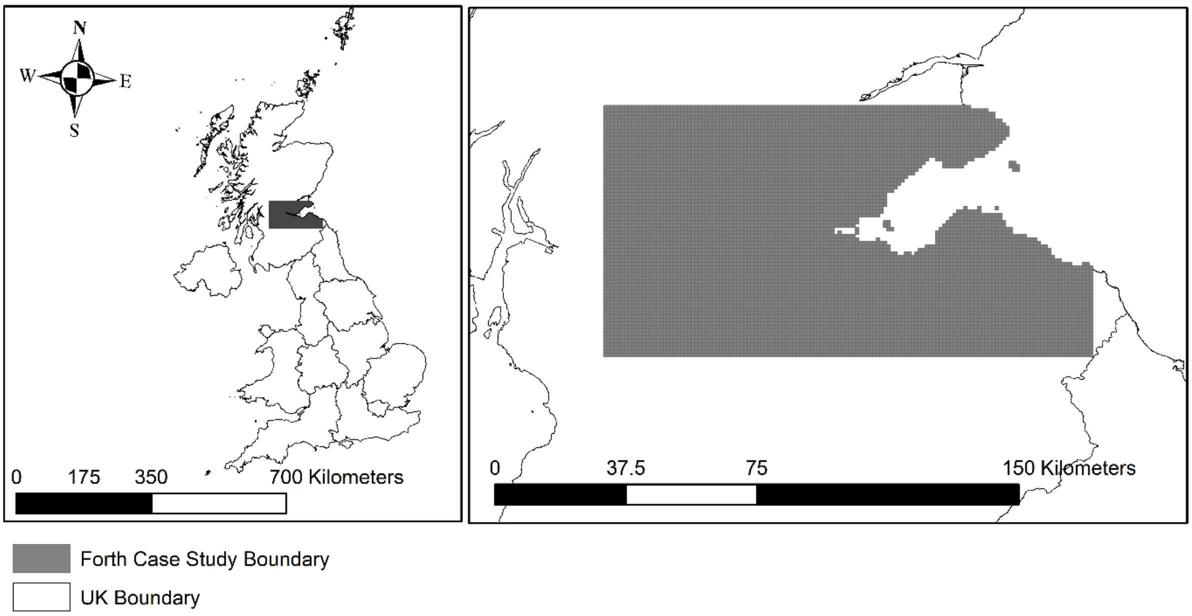

Figure 2: Case study location

[4] Needham et al (2020) look at No Net Loss in the Tees Estuary, England.

4. Results

Recall our first research question: how does the equilibrium market-clearing price of offsets vary according to an increasing requirement for biodiversity net gain? Within Proposition 1, we showed that the effect of increasing the net gain requirements on the equilibrium quantity (and price) of offsets is ambiguous. That is, a biodiversity net-gain policy initially increases (decreases) the equilibrium quantity and equilibrium offset price if offset demand at the no net loss equilibrium is inelastic (elastic). For our case study, we find that the price elasticity of demand at the no net loss equilibrium is -7.13 i.e., development demand in this system is highly elastic. As a consequence, we find that the price and quantity of offsets traded are highest at the no net loss policy target (Table 3). Under no net loss, the market-clearing price per lapwing offset is £16,433 and 232 trades take place. Both the number of trades and clearing price consistently decline as the net gain requirement increases: at 5% net gain 217 trades take place at a market-clearing price of £16,083 per lapwing, declining to 169 trades taking place at 50% net gain, with a market-clearing price of £14,137 per lapwing (Figure 3). As summarised in Section 2, moving from a no net loss to a net gain requirement, increases the demand for credits for each developer, with more offsets required per land parcel for development to be allowed to take place. However, this reduces their willingness to pay for a single offset, resulting in the demand curve for offsets shifting downwards and to the right. This is shown in Figure 4, where the demand curve is shown for the no net loss and 50% net gain policies.

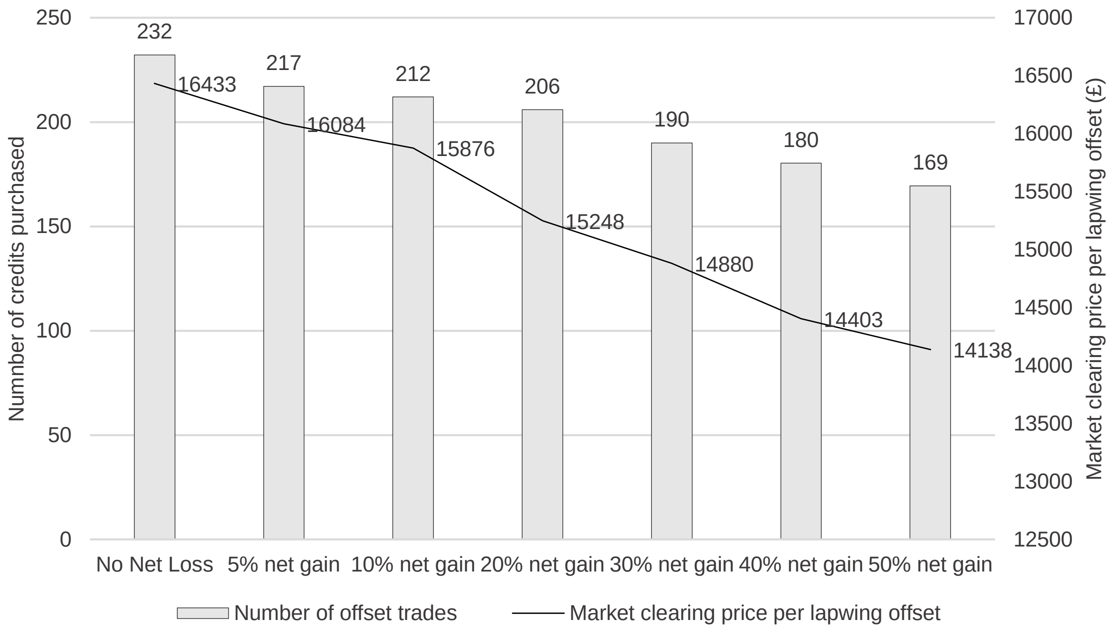

Figure 3: A comparison of the market clearing price per lapwing offset across the net gain scenarios

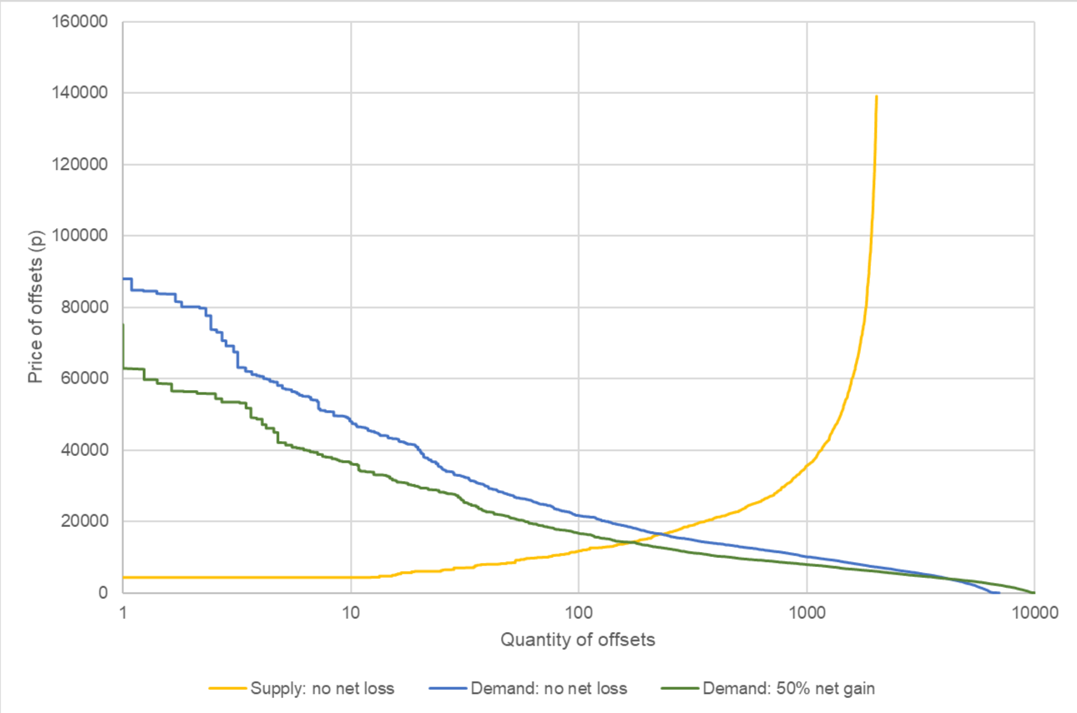

Figure 4: A comparison of offset supply and demand under no net loss and 50% net gain

Our second set of results considers the economic costs to developers of no net loss and net gain policies in comparison to development without biodiversity regulation (Table 1). Recall Scenario 1, where all land parcels which are profitable for housing are developed regardless of their biodiversity value, here 4066 land parcels are developed. In comparison, under Scenario 2 (no net loss), the number of land parcels developed declines to 1042 (a reduction of 3024 parcels) implying a cost to housebuilders of approximately £35 million in terms of revenues foregone – if we assume that the offset policy has no effect on house prices. As the net gain requirement increases from 5% net gain through to a 50% net gain requirement, we see a continued further decline in the number of land parcels developed, from 1018 under 5% net gain, down to 883 parcels developed under 50% net gain. Under 50% net gain the economic cost to the housing developers in terms of foregone housing retail value is greatest, at approximately £37 million.

Table 1: Overview of the change in economic costs as the biodiversity net gain requirement increases from no net loss through to 50% net gain.

	Scenario 1: No regulation	Scenario 2: No net loss	Scenario 3: 5% net gain	Scenario 4: 10% net gain	Scenario 5: 20% net gain	Scenario 6: 30% net gain	Scenario 7: 40% net gain	Scenario 8: 50% net gain
Market clearing price for an offset	n/a	16,432	16,083	15,876	15,247	14,880	14,402	14,137
Land parcels developed for housing	4066	1042	1018	999	966	930	911	883
Cost of offset purchase to house builders (million)	n/a	£3.80	£3.31	£3.06	£2.62	£2.16	£1.86	£1.59
Change in the number of lapwings	- 6991	0	+ 11	+19	+34	+45	+51	+57
Cost of foregone housing development (million)	0	£35.33	£35.75	£35.98	£36.36	£36.85	£37.17	£37.52

Finally, we can compare the ecological impacts of the no net loss and net gain policies, compared to a landscape with no offset policy in place. Under Scenario 1, where there is no offset policy in place, a total of 6991 lapwings are lost due to development taking place on 4066 land parcels. As expected, invoking a no net loss policy results in Scenario 2 results in no losses in lapwing: the offset market clears and 232 offset trades take place between buyers and sellers of credits to allow development to take place without net losses of lapwings across the case study area. Moving to a net gain policy in Scenarios 3 – 8 has two effects on abundances of lapwing. Firstly, the shift towards net gain results in fewer land parcels being developed as development is now less profitable, and subsequently, fewer lapwings are lost due to development impacts. Secondly, a move from a no net loss to a net gain policy requires developers to purchase more lapwing offsets than the number of lapwings lost due to development. For example, under the 5% net gain policy target, 1018 parcels are developed compared to 1042 under no net loss. This results in a reduction in the number of lapwings lost from 232 under no net loss to 206 under net gain. Under the 5% net gain target, developers are also required to increase the abundance of lapwing by 5%, resulting in the lapwing abundance increasing by 11 (217 lapwing offsets are purchased to compensate for the 206 lost to due development) (Table 2).

Table 2: A comparison of the lapwings lost at the market-clearing equilibrium due to development, and lapwings generated through offset supply sites across the range of policy scenarios

	Full development	No Net Loss	5% net gain	10% net gain	20% net gain	30% net gain	40% net gain	50% net gain
Lapwings lost at market clear	6991	232	206	193	172	145	129	112
Lapwings generated at market clear	0	232	217	212	206	190	180	169
Lapwing net gain			11	19	34	45	51	57

We can also explore these results spatially (Figure 5). Under Scenario 1 without development restrictions, it is clear that there would be a sustained high level of development throughout the case study region, particularly in the northwestern and southeastern parts of the study domain. Moreover, there would be high losses of lapwing from the land parcels that would be converted in this scenario: more five or more lapwings are lost on 115 parcels. Under Scenario 2 (no net loss), several predictions change. First, there is less new development. As Figure 4 makes clear, the steep increase in the supply curve once we get beyond 235 offsets would make further development unprofitable under a no net loss policy. At the same time, there is still some new development throughout the region, particularly in the northeastern part of the study area. Second, what development does occur avoids parcels that are particularly valuable to lapwing currently and thus would require a large numbers of offsets to be purchased if developed. In the majority of developed land parcels the number of lapwings lost falls below 2. Third, these losses are offset through the creation of lapwing offset supply sites, where bird populations increase. These offset supply sites are located throughout the case study region rather than being concentrated in one specific area, although more occur north of the Firth of the Forth (the major river in the maps) and closer to the coastline to the east.

Moving from Scenario 2 (no net loss) to Scenarios 3 – 8 (5% net gain through to 50% net gain) more predictions change. Firstly, we see a further reduction in development, this is in line with our previous discussions that net gain requirements make development more expensive. Development ceases on all land parcels where more than 5 lapwings are required to be offset (recall under 50% net gain, a land parcel containing 6 lapwings, for example, would be required to purchase 9 lapwing offsets). Under the 50% net gain scenario development only takes place on parcels requiring less than 2 lapwings to be offset. The concentration of development also reduces, particularly in the northwestern portion of the case study region. Across the net gain scenarios, the number of offset supply sites remains broadly constant across the scenarios with each offset supply site choosing to supply more or fewer offsets depending on the market price of the offset credit.

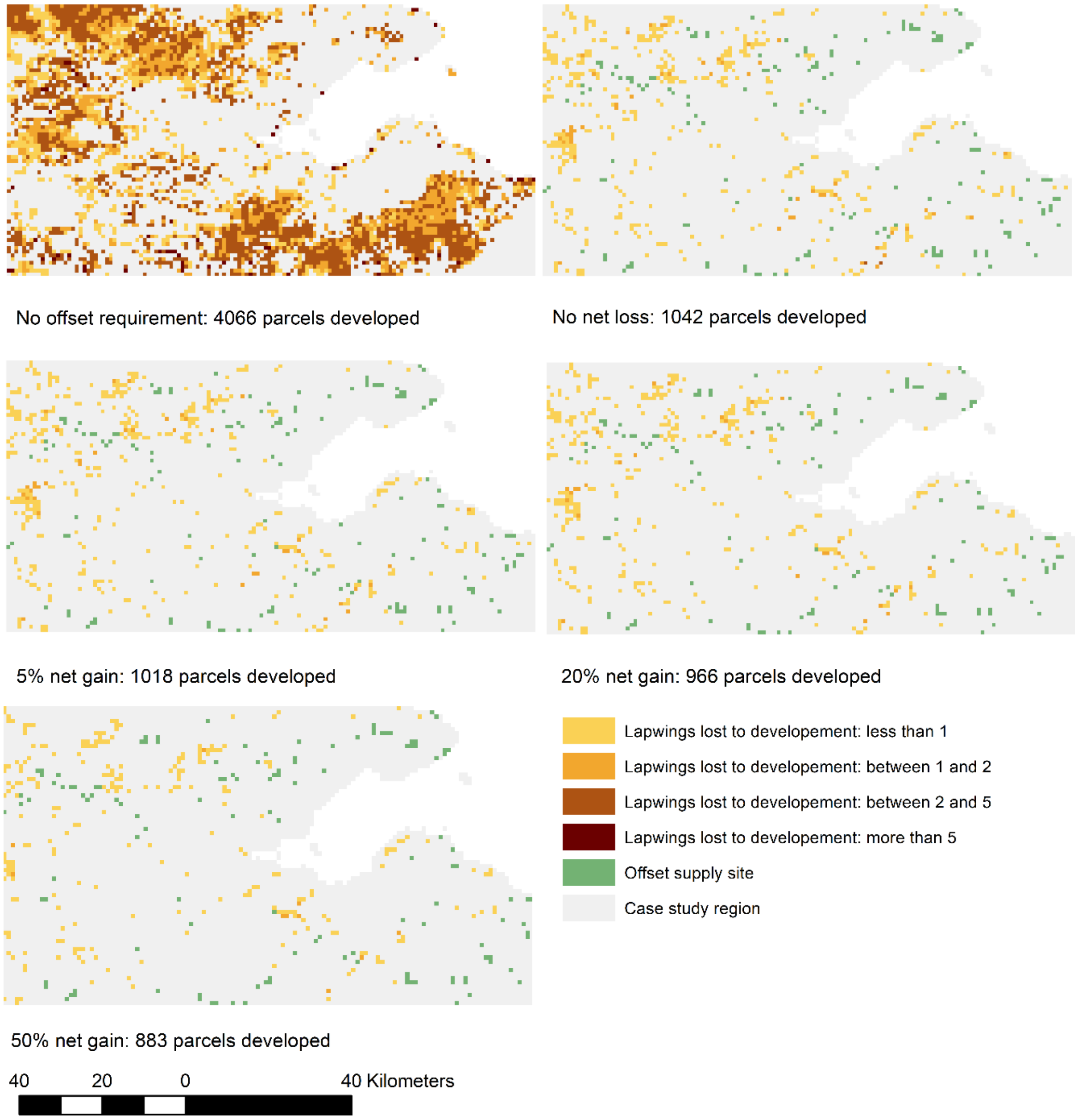

Figure 5: A comparison of development impacts across alternative net gain policy options

5. Discussion and conclusion

Globally, there is a growing movement towards conservation policies which focus on a net gain in biodiversity (Maron et al 2020). As part of these policies, developers are required by regulators to deliver a net gain in biodiversity alongside new infrastructure developments that negatively impact existing habitats and species. One option to deliver this net gain is a market for biodiversity offsets, whereby the regulator creates a market in valuable credits by imposing the offset requirement on developers, akin to a cap-and-trade pollution permit market. Tradeable offset credits offer one way in which developers can secure biodiversity net gain as part of their development plans. Our paper contributes to the emerging literature on biodiversity net gain (see Bull and Brownlie (2017), Jones et al (2019), Maron et al (2020), Simmonds et al (2020) and Weissgerber (2020) by developing an integrated economic-ecological model that allows us to compare the economic and ecological effects of different requirements of biodiversity net gain. We compare eight different policy scenarios, ranging from Scenario 1 where there is no conservation policy in place; Scenario 2 where there is a no net loss policy in place and Scenarios 3 – 8 where there is an increasing net gain requirement from 5% to 50% net gain. This allows us to explore how these different policies affect the demand for offset credits, in turn affecting the market price of a credit, how many trades take place between buyers and sellers of credits and the resulting ecological landscape.

Our theoretical model predicts that the effect of increasing the net gain requirements on the equilibrium quantity (and price) of offsets is ambiguous and case-dependent. That is, a biodiversity net-gain policy initially increases (decreases) the equilibrium quantity and equilibrium offset price if offset demand at the no net loss equilibrium is inelastic (elastic). This is an interesting finding in itself, suggesting that the impacts of a biodiversity offset market are likely to vary according to local supply and demand conditions. Using empirical modelling for a specific case study area, we find that increasing the net gain requirement from no net loss through to a 50% net gain requirement decreases both the market equilibrium price of offsets and the number of offset trades taking place. This effect is consistent throughout the net gain scenarios. As the number of lapwing offsets required by developers increases due to the changing net gain requirements from 5% through to 50%, the developers' willingness to pay for each offset declines. This results in a decline in the offset price from £16,433 per lapwing under the no net loss scenario to £14,138 per lapwing under the 50% net gain scenario. Additionally, the number of trades decreases from 232 under the no net loss policy requirement, to 217 under 5% net gain down to 169 credits at 50% net gain.

We thus see a continual reduction in demand for offset credits as the net gain requirements become stricter. As the number of offsets traded falls, the number of parcels on which new housing is developed also falls, from 1042 parcels under no net less to 883 under a 50% net gain target. This imposes costs on developers in terms of foregone profits from house building (assuming no effect from the offset scheme itself on house prices). The change in policy from no net loss to net gain does not shift the offset supply curve, since changing the regulatory requirement does not affect the ecological potential of land, or agricultural profits which can be obtained from this land. However, as the market-clearing price for the offset declines, fewer landowners choose to supply offsets, and thus less land is converted to conservation use.

Within our case study, there was a low level of offsets supplied at the market-clearing price across all the modelled scenarios, despite 1400 parcels being able to offer lapwing offsets. This low level of supply mirrors some of the current problems in developing biodiversity offset markets within the UK. The first round of biodiversity offset pilot studies took place from 2012 – 2014 in the UK and a limited number of landowners chose to engage with the pilots. Landowners voiced concerns over the costs of long-term management of offset sites, and the appropriate timescale of offset provision taking into account climate change, future development for land, and cumulative development pressures in the local area (Sullivan and Hannis 2015). This lack of involvement from potential offset suppliers resulted in no offsets being secured in the UK pilot studies. Following the mandating of biodiversity net gain within the 25 Year Environment Plan, there is now a pressing need to re-engage with agricultural landowners who could potentially supply biodiversity offsets. In particular, incentive structures need to be revisited, with schemes needing to capture the full scale of the opportunity costs associated with converting land from agricultural to biodiversity offsets (James, Gaston and Balmford, 1999). The UK Government is currently revising UK agricultural subsidies through the new Environmental Landscape Management scheme which replaces the EU's Common Agricultural Policy. Through this, there is a shift from agricultural subsidies to payment for public goods (Bateman and Balmford 2018). One can view the use of markets in biodiversity offsets with a net gain requirement as re-enforcing this change, but here the increase in the supply of public goods (more farmland birds) is being paid for by the private sector (house builders and thus, by implication, house buyers), rather than the public sector via taxpayer funds. Whilst there are clearly overlaps between who is a taxpayer, who is a house buyer and who owns shares in house building firms, there will be distributional impacts from a switch away from PES schemes and towards offset markets as a means of incentivising biodiversity conservation on private land.

As we would expect, the empirical results show that having any conservation policy in place, either no net loss or a level of net gain, is significantly more beneficial to biodiversity than allowing unrestricted development. Indeed, a scenario of completely unrestricted development leads to a loss of over 6000 lapwings in the case study region. In practice, there are already planning policies in place which reduce these negative impacts, including the EU Habitats and Wildbirds Directives (Directives Directive 92/43/EEC and 2009/147/EC) which designate sites as Special Protection Areas (SPAs) and

Special Areas for Conservation (SACs). These are not captured within our modelling framework. Moreover, pursuing a no net loss or net gain agenda benefits other aspects of biodiversity not protected by these designations (Conway et al 2013). This is especially crucial as climate change alters the range of many species and potentially moving species ranges beyond the currently protected area boundaries (Hoffmann, Irl and Beierkuhnlein 2019).

Whilst offset policies aim to fully offset biodiversity losses due to development, there are always concerns that, depending on the design of the offset scheme, the policy involves certain ecological losses but uncertain ecological gains (Weissgerber et al 2019). There will be time lags between a land parcel being developed and a supply site fully restored to a level where it is effective in providing suitable habitat to moderate the loss in biodiversity on developed sites. In such cases, there are conservation advantages from a banking approach, where credits can only be purchased once a certain level of conservation gains are realised and certified by either a government regulator or third party offset broker (Woodward and Kaiser 2002). Moreover, concerns have been raised about the ecological impacts of increasing the geographic scale of an offset market, even though this increase in scale may make the market more efficient (Needham et al, 2020; zu Ermgassen et al, 2020). However, these concerns should be placed in the context of rather mixed evidence on the biodiversity benefits of current agri-environmental policies within the European Union (Batary et al, 2015).

We recognise that our model does not implicitly capture the intricacies associated with ecological restoration. Indeed, our model is run over a single time period, which implies that there are no time lags between the offset loss and offset gain, and that the target species can readily move between the offset sites across the region. Further, we choose to focus on one specific ecological policy target (the abundance of lapwing) and a single restoration action (the conversion of cropland to zero-grazing grassland). Our model could be extended to capture an ecological policy target which focusses on no net loss, or a net gain of specific habitats rather than a single species, or an ecological metric capturing multiple bird species with varying restoration actions. This would then allow us to examine the ecological impacts of net gain policies which allow "out-of-kind" trading (zu Ermgasson et al, 2020). For example, with a focus on habitats, we could explore a market for environmental credits which ensure no net loss of a specific habitat, but also delivers gains in ecosystem services such as carbon storage or flood risk reduction. Finally, we have also not allowed for any change in house prices as a result of the operation of the offset market, although clearly localised changes in house prices could result from clusters of new developments. For insight into the possible indirect effects of a biodiversity offset market on non-target ecological indicators, and results on the implications of changing the geographic scale of the offset market, see Needham et al (2020).

As mentioned above, markets in biodiversity offsets have some similarities as an economic instrument with Tradeable Pollution Permits (TPP), since the regulator creates a valuable commodity by imposing a ceiling or cap on economic activity. In the offset market, this establishes a price which, in principle, could lead to the cost-effective allocation of land to conservation versus development, just as the permit price in a TPP market provides a signal to encourage least-cost abatement of pollution. A key difference, however, is in the supply side of these created markets. In a TPP market, the total supply of permits is determined by the regulator. Individual firms decide how many permits to buy and/or sell at a price which equates this exogenous aggregate supply to the aggregate demand curve for permits, which in turn depends on marginal abatement costs. In a market for offsets, in contrast, aggregate supply is endogenous: individual farmers compare the opportunity costs of agricultural production with the willingness to pay of housebuilders to determine how many offsets to create and then supply, although the regulator established the maximum permissible overall impact of economic activity on the environmental outcome in focus (here, birds). However, an interesting and largely-unexplored research question is what lessons we can learn from TPP markets which apply to markets in biodiversity offsets (Needham et al, 2019).

Finally, whilst we have employed data from a specific UK case study, our analysis provides an approach which is generalizable across countries looking to expand net gain policies and biodiversity offset markets. It would be interesting to replicate this approach across varying ecological, agricultural and development gradients, and to figure out what matters most in determining the direction and extent of changes in economic and ecological outcomes of an offset market as the net gain target is increased.

6. References

Arlidge, W.N., Bull, J.W., Addison, P.F., Burgass, M.J., Gianuca, D., Gorham, T.M., Jacob, C., Shumway, N., Sinclair, S.P., Watson, J.E. and Wilcox, C., 2018. A global mitigation hierarchy for nature conservation. BioScience, 68(5), pp.336-347.

Batary P, Dicks V., Kliejn D., and Sutherland W. (2015) "The role of agri-environmental schemes in conservation" *Conservation Biology*, 29 (4), 1006-116.

Bateman, I.J. and Balmford, B., 2018. Public funding for public goods: A post-Brexit perspective on principles for agricultural policy. Land Use Policy, 79, pp.293-300.

BBOP (Business and Biodiversity Offsets Programme), 2009. Biodiversity offset design handbook.

Bull, J.W. and Brownlie, S., 2017. The transition from no net loss to a net gain of biodiversity is far from trivial. Oryx, 51(1), pp.53-59.

Bull, J.W. and Strange, N., 2018. The global extent of biodiversity offset implementation under no net loss policies. Nature Sustainability, 1(12), pp.790-798.

Bull, J.W., Lloyd, S.P. and Strange, N., 2017. Implementation gap between the theory and practice of biodiversity offset multipliers. Conservation Letters, 10(6), pp.656-669.

CIEEM, C., IEMA.(2016). Biodiversity net gain: Good practice principles for development.

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., Larigauderie, A., Adhikari, J.R., Arico, S., Báldi, A. and Bartuska, A., 2015. The IPBES Conceptual Framework—connecting nature and people. Current Opinion in Environmental Sustainability, 14, pp.1-16.

Gibbons, P. and Lindenmayer, D.B., 2007. Offsets for land clearing: no net loss or the tail wagging the dog?. Ecological Management & Restoration, 8(1), pp.26-31.

Gordon, A., Bull, J.W., Wilcox, C. and Maron, M., 2015. Perverse incentives risk undermining biodiversity offset policies. Journal of Applied Ecology, 52(2), pp.532-537.

HM Government U.K. (2018). 25 Year Environment Plan. Retrieved from ww.gov.uk/government/publications.

Hoffmann, S., Irl, S.D. and Beierkuhnlein, C., 2019. Predicted climate shifts within terrestrial protected areas worldwide. Nature communications, 10(1), pp.1-10.

James, A.N., Gaston, K.J. and Balmford, A., 1999. Balancing the Earth's accounts. Nature, 401(6751), pp.323-324.

Jones, J.P.G., Bull, J.W., Roe, D., Baker, J., Griffiths, V.F., Starkey, M., Sonter, L.J. and Milner-Gulland, E.J., 2019. Net gain: seeking better outcomes for local people when mitigating biodiversity loss from development. One Earth, 1(2), pp.195-201.

Laitila, J., Moilanen, A. and Pouzols, F.M., 2014. A method for calculating minimum biodiversity offset multipliers accounting for time discounting, additionality and permanence. Methods in Ecology and Evolution, 5(11), pp.1247-1254.

Liu, P. and Swallow, S.K., 2018. Multi-Credit Market, Landowners' Responses, and Cost-Effectiveness of Credit Stacking Policy (No. 2108-2018-4557).

Maron, M., Brownlie, S., Bull, J.W., Evans, M.C., von Hase, A., Quétier, F., Watson, J.E. and Gordon, A., 2018. The many meanings of no net loss in environmental policy. Nature Sustainability, 1(1), pp.19-27.

Maron, M., Simmonds, J.S., Watson, J.E., Sonter, L.J., Bennun, L., Griffiths, V.F., Quétier, F., von Hase, A., Edwards, S., Rainey, H. and Bull, J.W., 2020. Global no net loss of natural ecosystems. Nature Ecology & Evolution, 4(1), pp.46-49.

Nature 2020. The United Nations must get its new biodiversity targets right. Editorial. Nature. 578, 337-338. doi: 10.1038/d41586-020-00450-5

Needham, K., de Vries, F.P., Armsworth, P.R. and Hanley, N., 2019. Designing markets for biodiversity offsets: Lessons from tradable pollution permits. Journal of Applied Ecology, 56(6), pp.1429-1435.

Needham, K., de Vries, F.P., Armsworth, P.R.., Dallimer, M. and Hanley, N., 2020. 'Understanding the Performance of Biodiversity Offset Markets: Evidence from An Integrated Ecological – Economic Model." Land Economics. In press.

Scottish Government. (2020). The Environment Strategy for Scotland: vision and outcomes. Retrieved from https://www.gov.scot/publications/environment-strategy-scotland-vision-outcomes/

Scottish Natural Heritage. (2019). Scottish Biodiversity Strategy . Retrieved May 23, 2020, from nature.scot website: https://www.nature.scot/scotlands-biodiversity/scottish-biodiversity-strategy

Simmonds, J.S., Sonter, L.J., Watson, J.E., Bennun, L., Costa, H.M., Dutson, G., Edwards, S., Grantham, H., Griffiths, V.F., Jones, J.P. and Kiesecker, J., 2020. Moving from biodiversity offsets to a target-based approach for ecological compensation. Conservation Letters, 13(2), p.e12695.

Sullivan, S. and Hannis, M., 2015. Nets and frames, losses and gains: Value struggles in engagements with biodiversity offsetting policy in England. Ecosystem Services, 15, pp.162-173.

United Nations, 2018. The sustainable development goals. UN.

Weissgerber, M., Roturier, S., Julliard, R. and Guillet, F., 2019. Biodiversity offsetting: Certainty of the net loss but uncertainty of the net gain. Biological Conservation, 237, pp.200-208.

Woodward, R.T. and Kaiser, R.A., 2002. Market structures for US water quality trading. Applied Economic Perspectives and Policy, 24(2), pp.366-383.

Zu Ermgassen S., Martine Maron, Christine M. Corlet Walker, Ascelin Gordon, Jeremy S. Simmonds, Niels Strange, Morgan Robertson, Joseph W. Bull (20200 “The hidden biodiversity risks of increasing flexibility in biodiversity offset trades” *Biological Conservation*, Volume 252,