Article

Evaluating Goal Programming as a Backcasting Tool to Assess the Impact of Local Stakeholder Determined Policies on the Future Provision of Ecosystem Services in Forested Landscapes

Edwin Corrigan * and Maarten Nieuwenhuis

University College Dublin (UCD) Forestry, School of Agriculture and Food Science, University College Dublin (UCD), Belfield, 4 Dublin, Ireland; maarten.nieuwenhuis@ucd.ie
* Correspondence: edwin.corrigan@ucd.ie; Tel.: +353-87-7552-666

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Abstract: Forest management in Ireland has traditionally focused on timber production and policies have been implemented with this in mind. Since the mid-1990s, the focus is transitioning from timber production to a more multifunctional forest management approach following the principles of sustainable forest management. A method known as “backcasting” has the potential to include local stakeholders into land-use and policy planning. Two case study areas were chosen to investigate the potential of backcasting for integrated forest landscape planning in Ireland: Western Peatlands and Newmarket. Potential beneficial policies produced by local stakeholders in participatory workshops were assessed for robustness using a goal programming model and the resulting changes in forest management and ecosystem service provisions were analysed. While each evaluated backcasting policy increased the provision of that policy’s targeted ecosystem service(s), it was at a cost to some others. The widening of buffer zones did reduce the landscape level risk to water sedimentation and the policy to enhance each landscape’s recreation potential did the intended. However, both policies reduced the amount of timber produced for most potential futures. The option of using genetically improved tree species showed potential to mitigate the effect of these policies on timber production. We present this study as a useful reference point toward evaluating the efficacy of a range of potentially implementable scenarios in Ireland. We believe the backcasting approach has promise for future use in other landscapes, given the success of this approach in our study. Given that much of the information required to model the ecosystem services was extracted from scientific research and datasets from outside of Ireland, the approach may well be useful for others seeking to do similar outside of Ireland.

Keywords: forest policy; potential futures; spatial planning; optimisation; remsoft woodstock; backcasting

1. Introduction

Irish forest management has traditionally focused on a timber production objective. This has shaped Irish forest policy. Since the mid-1990s, the objective of Irish forestry is transitioning from segregated management with a timber production focus to sustainable forest management (SFM). The economic, ecological and social “pillars” of SFM have to be addressed together when implementing the SFM management approach. In recent years, it has become apparent that the social pillar of SFM has been somewhat overshadowed by the other two pillars: The ecological pillar through increased political focus on conserving the hen harrier [1] and freshwater pearl mussel [2]; and the economic pillar in terms of producing timber to generate revenue [3].
Proper implementation of SFM will depend on an acceptable balance between the three pillars, as quantified by their indicators [4–6]. The utilitarian concept known as Ecosystem Services (ESs) can help to identify this balance [7]. The concept of ESs originated in late 1960s [8] and its evolution is described by Gómez-Baggethun et al. [9]. It was used in the 1970s to capture public interest in terms of biodiversity conservation [10]. From its starting point in the 1960s, the number of academic publications referring to ESs have gradually increased, leading to the Millennium Ecosystem Assessment, a major piece of work that provided an indication of the level of degradation of the provision levels of the world’s ESs [11]. Debate remains ongoing about the most appropriate and consistent method to define and quantify ESs. De Groot et al. [12] proposed indicators that link ESs to human well-being and they categorised the ESs as food, raw materials, climate regulation, gene pool protection, water regulation and recreation. In Ireland, political attention has focused on specific ESs, and some land-use conflicts have resulted in the identification of ESs that are strongly related to human welfare [13,14]. Research into these ESs has been initiated [13,15–17] and for this reason, a subset of ESs has been included in this study in the categories of timber production, carbon, biodiversity, water and recreation. These categories were chosen as they have arisen in various studies on land-use conflicts in Ireland [13,15,18].

Although consultation processes are in place, which include the public in operational forest decision-making for the purpose of Forest Stewardship Council (FSC) [19,20] and Programme for the Endorsement of Forest Certification (PEFC) [21] (i.e., consultation in relation to timber harvesting), the views and objectives of all stakeholders are not currently integrated into the forest planning process in Ireland. This study investigated “backcasting”, an approach designed to involve local level stakeholders (i.e., within two of the landscapes chosen for this study, Newmarket (NM) and Western Peatlands (WP)) into forest policy planning. The level of planning is initially intended to be at the local level but the ultimate aim is for this analysis to be useful at the EU level and to filter down to National level policies. Backcasting involves “working backwards from a particular desired future end-point to the present to determine what policy measures would be required to reach that future” ([22], p. 337). In this particular form of backcasting, the desired future is determined through engagement with users [22]. The method has been used in a Swedish study by Sandström et al. [23] where they applied participatory backcasting, comparing desirable forest futures among stakeholder groups, determining potential trajectories and identifying changes that were considered feasible and desirable. In a study in the Netherlands, the combination of exploratory scenarios and participative backcasting was evaluated and used in an analysis of the Dutch forest sector [24]. For this study, future forest management and policy approaches were formulated based on gathering the diverse knowledge and opinions of local level Irish stakeholders on their preferred ESs (outlined previously) and their provision levels (i.e., Corrigan and Nieuwenhuis [25]). The goal of this study is to assess the usefulness of goal programming (GP) in the development of a set of agreed and quantitatively evaluated backcasting policies that can be used in land-use policy discussions, and also to establish a proven framework for the future investigation of such policies in Ireland.

2. Materials and Methods

A description of the two case study areas (CSA), NM and WP, is presented in the following sections. These areas were chosen as they encompass two prominent forestry-related land-use issues in the Irish context that are also of interest for EU-level policy makers. The location of both CSAs is indicated in Figure 1 and relevant CSA statistics are included in Table 1.
Figure 1. Location of both case study areas: Western Peatlands (WP, top); and Newmarket (NM, bottom).
Table 1. Descriptive data associated with the WP and NM case study areas.

| Entire Case Study Area | Western Peatlands | Newmarket |
|------------------------|-------------------|-----------|
| Area (approximately in ha) | 1,060,000 | 188,000 |
| Forested area (approximately in ha) | 116,000 | 32,000 |
| Average temperature (°C) | 11–12 | 8–9 |
| Typical annual rainfall (mm) | West: 2000 East: 1200–1400 | 1200–1400 |

Forested land only (as of 2012)

| Forest ownership |
|------------------|
| Coillte | 64% | 68% |
| Private | 36% | 32% |

| Yield potential |
|-----------------|
| Productive forestry | 82% | 85% |
| Unproductive forestry | 18% | 15% |

| Age class distribution |
|-------------------------|
| 0–10 years | 26% | 14% |
| 11–20 years | 36% | 36% |
| 21–30 years | 19% | 28% |
| 31–40 years | 13% | 14% |
| 41–50 years | 5% | 6% |
| 51 years or over | 1% | 2% |

| Soil type |
|-----------|
| Brown earths and brown podzolics | 5% | 58% |
| Lithosols | 12% | 9% |
| Gleys/peaty gleys and gleyed grey brown podzolics | 17% | 26% |
| Flushed blanket peat | 48% | 7% |
| Cutaway raised bogs | 18% | 0% |

| Elevation |
|-----------|
| Less than 200 m | 93% | 26% |

| Distance to watercourse |
|-------------------------|
| Less than 200 m | 56% | 27% |
| Between 200 and 400 m | 26% | 28% |
| More than 400 m | 19% | 45% |

1 Forestry that has a Sitka spruce yield class equivalent of 14 m³ ha⁻¹ yr⁻¹ or higher is considered economically viable and hence productive [19].

2.1. Western Peatlands

The WP CSA was located in the northwest of Ireland. It is based on one of eight business area units, the method of land division and management used by Coillte, the Irish Forestry Board. Business area unit boundaries followed townland boundaries to a very large extent and each business area unit was designed to be an independently profitable unit. The location of the WP CSA meant that wind exposure was a dominant factor for all land-use options. The landscape issues investigated here focused on current forestry at the time and there was very little afforestation taking place. Hence, only the forests in the CSA at the beginning of the planning horizon were considered. Approximately 62% of the forests in the CSA have a peatland soil type, which is more than the national level of 44% [25]. This CSA, therefore, focused on an analysis of management approaches and ES provision of Ireland’s peatland forests. The high levels of rainfall and artificial fertilisation required to establish forests on the poor soils in the WP mean that forests, especially when reaching commercial maturity and clear-felling, may have environmental and ecological impacts, specifically in relation to several special areas of
conservation in the CSA associated with populations of the freshwater pearl mussel (*Margaritifera margaritifera*). In the mid-1900s, large areas of forest were planted with the use of artificial fertiliser. Environmental regulations are now more restrictive, and fertilisation is largely prohibited in the area. A conflict arises after harvesting, as reforestation is not possible due to poor soil fertility, although it is a requirement under Irish forest policy.

2.2. Newmarket

The NM CSA took in the north of county Cork. Dairying is the major farm enterprise in the NM CSA. Tillage is also quite substantial but was confined to the most fertile sites in the eastern parts of the CSA. There were strong regional variations in terms of farm scales and incomes. Farms located at lower elevations that were mainly specialising in dairying and tillage production tended to be bigger and more economically viable than smaller farms located in the hills that rely on cattle and sheep farming. Forests were almost exclusively located in the less fertile, upland areas of the CSA. NM was chosen to represent a landscape that has been undergoing extensive afforestation over the last 30 years, which has been perceived by the local community to negatively influence the cultural and social tradition of agriculture in the area [14]. In contrast to the WP CSA, both forest and agriculture were included in this study, to reflect the substantial afforestation programme that is continuing in this CSA past the time of publication.

2.3. Ecosystem Service Quantification

A summary of the ESs that the model can quantify is presented in Table 2 and a detailed description of how the sources were translated into the model for ES quantification is outlined in Corrigan and Nieuwenhuis [26].

| Ecosystem Service          | Range */Unit | Source                                                                 |
|----------------------------|--------------|------------------------------------------------------------------------|
| Timber                     | m³           | Forest growth and yield models used from British Forestry Commission (BFC) [27] |
| Deer cover                 | 1–10         | Relative suitability scores for forest land [28] **                    |
| Deer forage                | 1–10         | Relative suitability scores for forest land [28] **                    |
| Hen harrier                | 1–10         | [29–31] for forest land-uses, a distinction was made between first and subsequent rotation forests ** |
| Water sedimentation risk   | 1–100        | To indicate risk level based on soil type, upslope contributing area, distance from watercourse and land-use |
| Carbon                     | Tons Carbon (TC) | For conifers, individual tree root:shoot ratios from [33] and multiplied by the stems ha⁻¹; For broadleaves, aboveground biomass on stand level based on equations from [34] and belowground biomass using [35]. Basic density for species from [36] and it was assumed that 50% of biomass was carbon [37] |
| Red squirrel               | 1–10         | The relative suitability of canopy and species as a food source [38–42] |
| Nesting birds              | 1–10         | For forests, species richness information from sampling published in [43,44] ** |
| Ground vegetation          | 1–10         | For forests, species richness information from sampling published in [43,44] ** |
| Recreation                 | 1–10         | Scores for the Great Britain region were used [45]; a member of the Agricultural Ecology group determined relative permanence and structure of agricultural land-uses. Relative recreation scores were then assigned |

* If a scale is specified, the minimum and maximum values for each ES were assigned the minimum and maximum values in the range; ** Delphi method with Agricultural Ecology group in University College Dublin for agricultural land-uses.
2.4. Backcasting Policies

A qualitative scenario building process produced, through interviews and workshops with local stakeholders, scenarios that were plausible to happen in the future of the CSA (future meaning by the year 2042 from the start year of 2012) [46]. From this point on, these scenarios will be referred to as potential futures (PFs). These PFs were based on factors (known as key factors) which are, according to the stakeholders’ expert knowledge, most likely to influence forest and land-use management within the CSA in the future. Each column header in Table 3 represents a key factor and the rows represent a key factor change from the situation in 2012. Local level stakeholders were the individuals that operate and interact with other local stakeholders to achieve their objective in terms of land-use management in the CSA. They represented organisations which collectively provided a diverse range of perspectives on forestry in Ireland, including statutory regulatory bodies, commercial forestry companies, sawmilling industry, governmental and non-governmental environmental, ecology, cultural and heritage organisations and forest research institutions. The workshops were part of a larger socio-economic study and involved the discussion of some detailed forestry topics. For example, how current Irish forestry policy and forest growth and yield metrics might be affected on the stand and landscape level with the implementation of potential backcasting policies. This technical nature meant that care had to be taken to invite stakeholders from a larger list of those interviewed as part of [18], who had sufficient scientific and local knowledge of forestry to be able to follow the workshop dialogue [47]. A full local level stakeholder list and their involvement in the WP CSA can be found in Table A1 (Appendix A), this information is available in [46] for the NM CSA. The PFs are in the form of consistent combinations (i.e., combinations of key factor manifestations that were perceived as likely to happen in the same PF, for example, demand for pulpwod increasing and the establishment of a CHP plant in the CSA is considered as consistent; the establishment of a CHP plant was not considered consistent with a decrease in pulpwod demand) of future changes of these key factors. In collaboration with these stakeholders, qualitative scenarios were translated into metrics and modelled. The PFs for the WP CSA are summarised in Table 3, while the PFs for NM are summarised in Table 4. One of the PFs in each CSA was a business as usual (BAU) scenario, where current forest policy and current actor behaviour were assumed not to change for the duration of the planning horizon. The BAU PF was used as a baseline, against which all other PFs were compared. Even though the desired ES provision points were determined for the year 2042, the PF were modelled for a period of 70 years. This was to allow for the long-term effect of new policies on management approaches and ES provision levels to be analysed.

Table 3. Summarising the potential futures (rows) in terms of the key factors (columns) for the NM case study area (CSA). Source: Corrigan [48].

| Potential Future | Forest Certification * | Demand for Pulpwood | Demand for Sawnwood | Forest Policies and Regulations *** | Afforestation Premiums |
|------------------|-----------------------|---------------------|---------------------|-----------------------------------|------------------------|
| BAU              | Same **               | Same                | Same                | Same                              | Same                   |
| 2                | Same                  | 10% increase in price | 10% increase in price | Same                              | Same                   |
| 3                | Attitude change only  | 10% increase in price | Same                | Water measures                    | New afforestation grants and premiums removed from 2012 onwards |
| 4                | Same                  | Same                | 10% decrease in price | Water measures                    | All afforestation premiums are increased by 20% |

* Publicly owned forests were certified under Forestry Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification (PEFC), privately owned forests were not. The attitude change only indicates that some key biodiversity ESs were included within the optimisation algorithm (i.e., deer forage, deer cover and hen harrier). These were chosen because deer habitat is of importance to Irish stakeholders, while there was current land-use conflict in relation to hen harriers in this CSA; ** Same refers to the situation of each key factor (policy, certification or market) as of 2012; *** The water sedimentation risk ES was included in the optimisation algorithm to represent that it was a consideration in land-use management.
Table 4. Summarising the potential futures (rows) in terms of the key factors (columns) for the Western Peatland case study area. Source: Corrigan and Nieuwenhuis [49].

| Potential Future | Demand for Sawnwood | Demand for Pulpwood | Demand for Rural Development * | Water Protection ** | Replanting Requirement *** | Sustainable Forest Management (SFM) **** |
|-----------------|---------------------|---------------------|-------------------------------|---------------------|---------------------------|-----------------------------------------|
| Business As Usual (BAU) | Same | Same | No combined heat and power (CHP) plant | Same | Same | Same |
| 2 | Same | Same | No CHP plant | Same | Lifted | Same |
| 3 | 10% increase in price | 10% increase in price | CHP plant built | Same | Same | Same |
| 4 | 10% increase in price | 10% increase in price | CHP plant built | Water measures | Same | SFM measures |
| 5 | Same | Same | No CHP plant | Water measures | Same | SFM measures |

* The WP was experiencing rural depopulation and much of the timber produced in the area was processed out of the area. The idea was that a large CHP plant will mean that individuals in the area could be employed and, overall, view forestry as a positive to the CSA; ** The water sedimentation risk ES was included in the optimisation algorithm to represent that it was a consideration in land-use management; *** In Ireland, if a forest was clear-felled, it was mandatory to replant; **** Publicly owned forests were certified, privately owned ones were not. “SFM measures” indicates that some key biodiversity ESs were included within the optimisation algorithm (i.e., deer forage and deer cover). These were chosen as deer habitat is of importance to Irish stakeholders.

The modelled ES provision levels for each PF were presented to a group of local stakeholders [47] (including many of those also involved in the development of the potential future scenarios) in each CSA. The stakeholders who participated in these workshops had two main tasks:

- They were asked to outline their desired ES provision levels by the year 2042, with 2012 ES provisions as a starting point [26];
- Based on their desired provision levels in 2042, they were asked to identify policies that could be implemented in 2012 that would move the provision of ESs in the desired direction from the levels in 2012.

The result of these workshops was a list of policy actions. An initial presentation of PFs and corresponding ES provisions was given and used to frame the scope of the workshop. Then an open discussion between stakeholders yielded the list of policy actions. They are outlined in [47], for each CSA. These policies were agreed by eventual consensus, through group discussion between the entire stakeholder group. Examples of the policies are increased training of private forest owners to achieve higher timber production, planting of alternative species in watercourse buffer areas, the planting of large homogenous blocks of suitable species to benefit red squirrel habitat, reducing maximum allowable clear-fell area to benefit water quality and the planting of more broadleaved species for recreation purposes. After the stakeholder discussion in each CSA, there was an informal feedback session. Participants were asked to comment on the transparency of the process and for their thoughts on the decision support system and especially on the choice of GP. The list was reviewed for this study and two suggested backcasting policies per CSA were selected (described in detail later in this section) to determine if these policy measures, individually and combined, will achieve the desired effect on ES provisions when applied to all potential futures (i.e., a robustness assessment). The backcasting policies assessed for robustness were selected based on the feasibility of implementing them in the GP model, our trained perception on model responsiveness and the potential that they could be introduced as national policies. A policy was considered robust if more than half of the PFs had provisions of ES moving in the desired direction. A policy was; therefore, considered robust if three of the four PFs in NM and three of the five PFs in WP met this criterion. Each backcasting policy was first implemented individually in each PF and then the two policies were combined, so that they could be assessed for compatibility.
2.5. Goal Programming Model and Backcasting Policies

The objective function value was a combination of PF specific ESs. The ES goals are based on optimising the included ESs separately. The highest biophysical ES provision was used except for water sedimentation risk, where the lowest ES provision scenario was used. Even though net present value (NPV) was not an ES, it was included in this paper in the list of ESs as it was an important factor in the decision-making process. The scales that quantify ESs are different and their maximum and minimum ranges vary. Therefore, a normalisation procedure was implemented so that deviations from each goal were comparable. Goals were specified as constraints for each owner type (OT; i.e., a mutually exclusive landowner type: Coillte, private forest owners, agricultural ruminant production or tillage landowners). The area occupied by each OT was spatially delineated and it was assumed that all members in an OT group will respond to policy changes in a similar manner. OT specific attitude differences were incorporated in the model through the scaling of the normalised weights in the goal programming objective function. Constraints ensured that ineligible management prescriptions were not prescribed within politically designated zones. Evenness constraints were also included to ensure that there is a controlled supply of timber for each product assortment category (pulp, stake, small and large sawlog) over the planning horizon.

The changes made to this model to investigate the backcasting policies are described in more detail in the following sections.

2.5.1. Backcasting Policy 1: Genetically Improved Sitka Spruce (GI)

The first backcasting policy assessed for robustness in NM only was the optional introduction of genetically improved (GI) Sitka spruce (SS) plants for any site which undergoes afforestation or reforestation. The yield class for the entire stand planted with SS was assumed to increase by two standard yield classes when GI planting stock was used (e.g., Yield Class (YC) 18 to YC 20). It was assumed that GI material makes up 50% of the planted SS stock and the extra cost of these plants (i.e., a total extra establishment cost of €184 ha⁻¹, Phillips and Thompson [50]) was included in the model. This policy was implemented in the model in the form of two extra establishment options. They are like two existing establishment options, the difference was that unimproved SS is replaced with GI SS; these options are to establish GI SS with a 20% mix of broadleaves (sycamore, ash or birch) and 30% unimproved Sitka spruce or with a 20% mix of Norway spruce and 30% unimproved Sitka spruce.

2.5.2. Backcasting Policy 2: Subsidised Mandatory Public Access for All Forests (Rec)

The second backcasting policy, subsidised mandatory public access for all forests (Rec), was assessed for robustness in both WPs and NM. It was to make public access mandatory for all forests. In 2012, Coillte already had a policy where all forests are open to the public, so the new policy only impacts on forests owned by private landowners. They will be subsidised based on the suitability of their forest for recreation. These subsidies are based on suitability scores for recreation [45]. The subsidy level was calculated, by the authors, by multiplying the recreation score for a forest type by a factor of 5 and this annual amount per hectare is paid to the owner of that forest type and development stage (Table 5). The incentive was paid over the entire 70-year planning horizon. The average willingness to pay value of €5.42 per visit to a forest was obtained from [51]. It was not possible to get real visitor numbers for all forests in Ireland, so for want of better data, the assumption was made that the scores represent relative visitor numbers and the factor 5 represents the value of one visit.
Table 5. Recreational subsidy provided to private forest owners on a € ha$^{-1}$ yr$^{-1}$ basis (i.e., it depends on the forest type and development stage of the forest).

| Development Stage | Native Woodland Site | Continuous Cover Forestry | Traditional Forest Management |
|-------------------|----------------------|---------------------------|-----------------------------|
|                   | Conifer | BL$^1$ | Mixed | Conifer | BL | Mixed | Conifer | BL | Mixed |
| Establishment     | 15.00   | 17.50  | 20.00 | 15.00   | 17.50 | 17.50 | 5.00    | 12.50 | 12.50 |
| Young             | 15.00   | 30.00  | 25.00 | 15.00   | 25.00 | 25.00 | 10.00   | 17.50 | 20.00 |
| Medium            | 25.00   | 40.00  | 40.00 | 30.00   | 37.50 | 32.50 | 15.00   | 25.00 | 25.00 |
| Adult             | 35.00   | 50.00  | 45.00 | 32.50   | 40.00 | 42.50 | 22.50   | 30.00 | 30.00 |

$^1$ BL = Broadleaf.

As part of this policy implementation, the recreation ES was included in the objective function of the goal programming formulation to reflect an attitude change, using different utility factors for the different owner types (Table 6).

Table 6. Forest owner type specific utility factors applied to the recreation ES in the objective function of the Goal Programming (GP) optimisation.

| Owner Type                | Utility Factor |
|---------------------------|----------------|
| Coillte                   | 0.00           |
| Private forest owners     | 0.50           |
| Tillage farmers           | 0.75           |
| Ruminant farmers          | 1.00           |

2.5.3. Backcasting Policy 3: Introduction of Measures to Reduce Water Sedimentation Risk (Water)

The third backcasting policy was only applied in the WP CSA. It introduces a series of measures that are designed to simultaneously reduce water sedimentation risk (Water) and produce more timber, or at least limit the reduction in the production of timber that could be associated with these sedimentation risk reduction measures. The levels of provision of these two ESs were considered pivotal to the future of forestry in the WP landscape. The water sedimentation risk ES was included in the objective function of the GP model to reflect a uniform attitude change for all owner types.

The width of water related buffer zones was increased in this backcasting policy. PFs in which buffer zones had not already been doubled in width (compared to the buffer width in the BAU scenario), had buffer zone widths doubled in this backcasting policy (PFs 1, 2 and 3), while in the PFs where width had already been doubled, the new width was triple the original buffer zone width (PFs 4 and 5). The management options for all forests within these buffer zones were: clear-felling followed by buffer zone establishment with buffer type 1 (i.e., sparsely replanting areas within a certain proximity of a watercourse with broadleaves while leaving the remainder open); or the use of CCF (continuous cover forestry) principles, where felling takes place motor-manually and extraction is carried out by cable system (buffer type 2). The ground is virtually undisturbed with the cable harvesting system, and it is assumed that the water sedimentation risk is the same as the risk associated with undisturbed forest, but it was still 20% higher than in established buffer type 1. If a stand in a buffer zone was too old for the introduction of CCF management (i.e., older than 41 years), an option was introduced to clear-fell it using chainsaw felling and cable extraction and reforest with a productive timber species, which must be managed by CCF (a choice between a range of conifer and broadleaf species), assuming no additional risk compared to an undisturbed forest. Any site managed as CCF was constrained to remain managed as CCF for the remainder of the planning horizon.

In addition to the water related policy buffer zones, timber harvested in forests outside of water policy-related buffer zones but within 1 km of any watercourse must have been extracted by cable system, but felled by harvester. This harvesting method was assumed to reduce the water sedimentation risk to 25% of what it would be if forwarder extraction was used.
The revenue generated from harvesting these sites is multiplied by a scaling factor, which is specific to a tree species, to reflect the higher cost associated with chainsaw felling and cable extraction operations compared to those by harvester and forwarder. It was estimated that felling and extraction costs were €3 m\(^{-3}\) higher for each operation for each product assortment. These additional costs were subtracted from the product assortment revenue based on harvester and forwarder used. The assortment values per m\(^3\) are summarised in Table 7. Based on these assumptions, the scaling factors were calculated based on the product assortments within each forest species group in the model. Little difference was observed between the scaling factors for the range of yield classes within a species group; therefore, the scaling factor for the least productive (thinned) yield class was used for each species group. By assuming the same harvesting penalty for all assortments (€3 m\(^{-3}\)), the relatively higher cost of harvesting and extracting smaller trees was considered. An example of the development of these scaling factors is presented in Table 8. This example shows that the revenue per hectare generated from the clear-fell of a Sitka spruce stand (of any yield class) based on the British Forestry Commission static yield tables [27] at age 38 will be multiplied by 0.894 to reflect the added cost of motor manual felling and cable extraction, compared to harvester felling and forwarder extraction.

| Harvesting System          | Pulp | Stake | Small Sawlog | Large Sawlog | Broadleaf (Firewood) |
|----------------------------|------|-------|--------------|--------------|----------------------|
| Harvester and forwarder    | 26   | 41    | 53           | 61           | 42                   |
| Harvester and cable system | 23   | 38    | 50           | 58           | 39                   |
| Motor manual and cable     | 20   | 35    | 47           | 55           | 36                   |

Table 7. Revenue (€ m\(^{-3}\)) of each product assortment sold standing for a range of harvesting and extraction practices. The value of a stand depends on the volume of each product assortment.

| Assortment | Volume (m\(^3\) ha\(^{-1}\)) | Harvester and Forwarder | Harvester and Cable Extraction | Motor Manual and Cable Extraction |
|------------|-------------------------------|-------------------------|-------------------------------|---------------------------------|
|            |                               | (No Change)             |                               |                                 |
| Pulp       | 16                            | 416.00                  | 368.00                        | 320.00                          |
| Stake      | 2                             | 82.00                   | 76.00                         | 70.00                           |
| Small sawlog | 79                            | 4187.00                 | 3950.00                       | 3713.00                         |
| Large sawlog | 175                           | 10,675.00               | 10,150.00                     | 9625.00                         |
| Total      | 272                           | 15,360.00               | 14,544.00                     | 13,728.00                       |

Table 8. Example of the calculation of the scaling factors for each harvest type using the clearfell volume of Sitka spruce with a yield class 14 at age 38.

2.5.4. National Level Stakeholder Involvement

The results of the backcasting policies were presented to a panel of three senior members of the Forest Service; this is the government body with responsibility for ensuring the sustainable development of forestry in Ireland. The purpose of the meeting was to determine if the modelled backcasting policies would be implementable within the Irish context. The meeting took a systematic format where each backcasting policy for both CSAs was described and then the potential of its practical implementation was discussed.
3. Results

The effect of each backcasting policy applied to each PF will be described in this section. First, the results for each backcasting policy will be described separately in terms of the resulting management approaches and ES provisions. The Rec backcasting policy was applied in both CSAs and hence its impact will be described for both CSAs in one section. Second, the effect of implementing two backcasting policies simultaneously in each CSA will be described.

When individual ES values are presented, they are the average ES values for the 70 years, while management approach proportions will focus on the proportion in the final year of the planning horizon only. The ES provision level of all ESs will be presented; however, detailed text descriptions will focus on only three ESs (i.e., water sedimentation risk, timber production and recreation). These ESs were chosen as they were the main focus of the backcasting policies and of discussions during the local stakeholder workshops.

3.1. Backcasting Policy 1: Genetically Improved Sitka Spruce (GI) (Newmarket Only)

There was an increase in the proportion of traditional forest management (i.e., forest with a segregated timber production focus) for all PFs (ranging from 0.6% to 1.5%) when the GI backcasting policy was applied. Fewer buffer zones were established by agricultural owner types as the priority was planting trees and, more specifically, planting improved stock for increased timber production. Implementation of this policy resulted in increased timber production in three of the four PFs. The higher productivity associated with GI SS means that stands reach commercial maturity at a younger age, which resulted in more frequent harvests, generating the same revenue from a smaller area. Considering that decisions are made in the GP optimisation algorithm, within pre-specified constraints, based only on net present value (NPV) in the BAU potential future, the GI backcasting policy when applied to BAU increased the risk of water sedimentation compared to the risk for the BAU scenario alone. In the other three PFs, in addition to NPV, other ESs, including water sedimentation risk, were taken into account, which had the effect that the level of water sedimentation risk was maintained (rather than increased).

When the GI backcasting policy was applied to the BAU scenario, the 70-year average timber production increased by circa 15,000 m$^3$, with similar increases observed when the GI backcasting policy was applied to PFs 2 and 4. But when the GI backcasting policy was applied to PF 3, the policy had little effect on timber production as the option of planting GI stock was rarely chosen. This is related to the nature of PF 3, where forest certification (through the inclusion of deer forage, deer cover and hen harrier in the GP optimisation) and more restrictive water protection measures encouraged landowners to become more environmentally focused.

3.2. Backcasting Policy 2: Public Access to All Forests (Rec)

3.2.1. Western Peatlands

When the Rec backcasting policy was implemented in all five PFs in the WP CSA, the proportions of forest managed using traditional forest management were lower than those in the corresponding PFs without the backcasting policy applied. The incentive toward enhancing forests for the provision of recreation meant that management approaches that provide mature stands and broadleaf species were chosen. This meant a shift from traditional forest management to the CCF and Native Woodland Site (NWS) approaches in all PFs, when the recreation backcasting policy is implemented. Even though not subsidised, more buffer zones (type 1) were also established because of the associated high recreational value. In areas with high recreation scores, water sedimentation risk was also reduced; for this reason, water sedimentation risk decreased (or is kept at the level in the PF) for all PFs, following the implementation of the Rec backcasting policy.

The subsidies that private forest owners received for the provision of forest recreation were an incentive to retain their stands past the age of commercial maturity. When NPV was viewed on an
entire CSA basis, this incentive was sufficient in all PFs to compensate the private forest owners for the revenue foregone by not clear-felling their stands.

3.2.2. Newmarket

When the Rec backcasting policy was applied in the NM CSA, the results were very similar to those for the WP CSA. This policy fulfilled the intended purpose of increasing the recreation provision in all four PFs. As in the WP CSA, the introduction of the Rec policy also reduced the water sedimentation risk. The proportion of CCF was particularly high for private forest owners, increasing by a minimum of 15% and up to a maximum of 65%, compared to the proportions in the respective PFs without the Rec policy. The recreation policy also influenced the area afforested. When subsidies for forest recreation were introduced and an attitude change took place towards recreation, more afforestation happened place while staying within the bounds of the afforestation budget (Table 9).

| Potential Future (PF) | Potential Future with Rec |
|-----------------------|--------------------------|
| BAU                   | 28.02%                   | 34.14%                   |
| 2                     | 28.29%                   | 34.12%                   |
| 3                     | 33.16%                   | 35.73%                   |
| 4                     | 34.62%                   | 37.50%                   |

When the Rec policy was applied to PFs BAU, 2 and 4, the NM CSA’s forests were harvested at a later stage and a higher proportion of the CSA was managed using the CCF and NWS approaches, which resulted in a decrease in timber production (Table 10). However, more timber was produced in PF 3 when the Rec policy was applied than in the original PF. There was little afforestation in the original PF 3 and existing forests were allowed to mature. Very little forest harvesting took place in these existing forests in order to accommodate the non-timber ESs in the optimisation (i.e., water sedimentation risk, deer forage and cover), while these non-timber ESs and hen harrier habitat provision were typically higher on non-forest land-uses. The same level of forest maturity was not required when the Rec policy was implemented as these non-timber ES goals were provided through an increase in the area afforested and more forested area was managed under CCF and as native woodland, both of which provided higher recreation scores (on a per hectare basis) than traditional forest management.

3.3. Backcasting Policy 3: Introduction of Measures to Reduce Water Sedimentation Risk (Water) (WP Only)

Widening buffer zones combined with the attitude changes to reduce water sedimentation risk and the option to produce timber in the buffer zones (i.e., the option to plant and harvest trees using low-impact methods), meant that there was a greater incentive to establish buffer zones, and the area managed as buffer zones increased when the Water backcasting policy is applied to all PFs. The area of buffer zone managed as type 2 (i.e., CCF) was typically half of the total area established as a buffer zone when the Water backcasting policy was applied to all PFs (Table 11). The main reason why buffer type 1 is established instead of buffer type 2 is that some areas were unproductive (i.e., YC ≤ 12). PF 2 had the lowest total uptake of buffer zone establishment as the low cost, non-reforested management approach was chosen over the costlier establishment of buffer zones. Buffer zones were wider in PFs 4 and 5 than in the other PFs, which resulted in higher proportions of buffer zone being established.
Table 10. Summary of the ES outputs (average values for the years 2012 to 2082) for all backcasting policies assessed for robustness in the NM CSA. The red cells highlight the ESs that, compared to their level in the PF, move away from the stakeholder desired endpoint when the backcasting policies are implemented; the green cells highlight a move towards the stakeholder desired endpoint; while the ESs in the cells with no shading are unchanged from those for the PF.

| Potential Future | Timber (m$^3$) | Deer Cover (1–10) | Deer Forage (1–10) | Hen Harrier (1–10) | Water Sedimentation Risk (0–100) | Carbon (T C) | Red Squirrel (1–10) | Nesting Birds (1–10) | Ground Vegetation (1–10) | Recreation (1–10) |
|------------------|----------------|-------------------|-------------------|-------------------|----------------------------------|--------------|---------------------|---------------------|-----------------------|------------------|
| Initial (2012)   | 329,705        | 2.18              | 5.14              | 4.67              | 6.25                             | 1,250,855    | 0.24                | 9.18                | 3.77                  | 2.61             |
| Desired          | 355,625        | 2.50              | 3.20              | 2.60              | 2.00                             | 6,750,000    | 2.20                | 8.79                | 3.80                  | 6.00             |
| BAU              | 337,577        | 2.28              | 5.20              | 4.27              | 6.31                             | 2,064,619    | 0.40                | 9.09                | 3.83                  | 2.75             |
| BAUGI            | 352,000        | 2.30              | 5.19              | 4.24              | 6.33                             | 2,051,228    | 0.41                | 9.09                | 3.82                  | 2.73             |
| BAURec           | 329,842        | 2.36              | 5.19              | 4.26              | 6.14                             | 2,284,492    | 0.48                | 9.00                | 3.9                   | 2.95             |
| BAUGI&Rec        | 329,642        | 2.36              | 5.19              | 4.26              | 6.14                             | 2,284,492    | 0.48                | 9.00                | 3.9                   | 2.95             |
| PF2              | 344,829        | 2.35              | 5.17              | 4.19              | 6.27                             | 2,016,714    | 0.41                | 9.06                | 3.81                  | 2.72             |
| PF2GI            | 347,853        | 2.35              | 5.16              | 4.18              | 6.27                             | 2,007,045    | 0.41                | 9.06                | 3.81                  | 2.72             |
| PF2Rec           | 335,375        | 2.36              | 5.19              | 4.26              | 6.14                             | 2,238,418    | 0.48                | 9.00                | 3.9                   | 2.94             |
| PF2GI&Rec        | 329,710        | 2.37              | 5.20              | 4.49              | 6.15                             | 2,288,900    | 0.46                | 9.00                | 3.9                   | 2.96             |
| PF3              | 85,989         | 2.58              | 5.34              | 4.68              | 5.44                             | 3,268,961    | 0.49                | 8.93                | 4.05                  | 3.19             |
| PF3GI            | 85,926         | 2.58              | 5.34              | 4.68              | 5.44                             | 3,278,134    | 0.48                | 8.93                | 4.05                  | 3.19             |
| PF3Rec           | 92,673         | 2.62              | 5.34              | 4.58              | 5.42                             | 3,461,891    | 0.55                | 8.87                | 4.07                  | 3.26             |
| PF3GI&Rec        | 93,109         | 2.62              | 5.34              | 4.58              | 5.42                             | 3,511,123    | 0.55                | 8.87                | 4.07                  | 3.26             |
| PF4              | 262,479        | 2.51              | 5.20              | 4.39              | 5.54                             | 2,444,454    | 0.54                | 8.95                | 3.94                  | 3.05             |
| PF4GI            | 268,076        | 2.51              | 5.20              | 4.40              | 5.54                             | 2,439,849    | 0.54                | 8.86                | 3.94                  | 3.04             |
| PF4Rec           | 258,883        | 2.49              | 5.24              | 4.36              | 5.62                             | 2,641,675    | 0.54                | 8.92                | 3.98                  | 3.19             |
| PF4GI&Rec        | 263,205        | 2.48              | 5.23              | 4.37              | 5.62                             | 2,634,293    | 0.54                | 8.92                | 3.98                  | 3.19             |

Note: the 2012 ES outputs and the desired levels, as determined by the stakeholders, are included. In the left column: PF = Potential future; GI = Genetically improved Sitka spruce (SS); Rec = Public access to all forests policy.
Table 11. Proportion (%) of WP CSA that is in buffer zone type 1 (scrub) and type 2 (Continuous Cover Forestry (CCF)) by the end of the planning horizon in each potential future, and as a result of implementing the Water backcasting policy.

| Potential Future | Potential Future Potential Future + Water Backcasting Policy |
|------------------|-----------------------------------------------------------|
|                  | Type 1 | Type 2 | Total   | Type 1 | Type 2 | Total     |
| BAU              | 3.59   | 0      | 3.59    | 1.91   | 2.88   | 4.79      |
| 2                | 2.74   | 0      | 2.74    | 1.50   | 1.64   | 3.14      |
| 3                | 3.59   | 0      | 3.59    | 1.65   | 3.04   | 4.69      |
| 4                | 4.83   | 0      | 4.83    | 3.28   | 2.64   | 5.92      |
| 5                | 6.36   | 0      | 6.36    | 4.20   | 2.57   | 6.77      |

The change in harvesting methods (i.e., chainsaw felling, cable extraction) and the wider buffer zones resulting from the implementation of the Water backcasting policy produce a much lower water sedimentation risk in all PFs (Table 12).

When the Water policy was applied to the BAU PF, water sedimentation risk was reduced by circa 28% compared with the water sedimentation risk associated with the original PF. This policy resulted in a decrease in timber produced in three of the five PFs. These are BAU, PF 2 and PF 3, while more timber was produced when the Water policy was applied to PFs 4 and 5. In PFs BAU, 2 and 3, a higher proportion of forest was managed by the CCF and buffer zone approaches which reduced water sedimentation risk. When the Water policy was applied to PFs 4 and 5, less bog was restored than in the corresponding PFs without the Water policy, along with less CCF management, and a much higher proportion of forest was managed with the traditional forest management approach by the end of the planning horizon. The cable extraction and chainsaw felling associated with the Water policy to reduce water sedimentation risk and, as a result of all of the above, in PFs 4 and 5, with the backcasting policy implemented, more timber was produced while the level of water sedimentation risk was reduced compared to the levels in the respective PFs alone.

3.4. Implementing Backcasting Policies Simultaneously

3.4.1. GI and Rec in Newmarket

The mature forests that were associated with high recreation values were harvested for timber production and revenue to be realised. This means that the GI and Rec policies were incompatible on an individual stand basis. The GI scenario on its own resulted in a lower average stand age when compared to the average age for the respective PFs, while the Rec scenario on its own produced the highest average stand age (with the exception of PF 3, as described previously). When both policies were implemented simultaneously, the average stand age was higher than in the PF and in between those for the GI and Rec backcasting policies for all PFs. The areas of older forest maintained the recreation scores (but still produced timber through CCF, albeit at a lower level), other areas of the landscape are planted with GI material and managed using the traditional approach, this produced more timber. So, the combined policies led to a segregated management approach at the landscape level (Table 12).
Table 12. Summary of the ES outputs (average values for the years 2012 to 2082) for all backcasting policies assessed for robustness in the WP CSA. The red cells highlight the ESs that, compared to their level in the PF, move away from the stakeholder desired endpoint when the backcasting policies are implemented; the green cells highlight a move towards the desired end point; while the ESs in the cells with no shading are unchanged from those for the PF.

| Potential Future | Timber (m$^3$) | Deer Cover (1–10) | Deer Forage (1–10) | Hen Harrier (1–10) | Water Sedimentation Risk (0–100) | Carbon (T C) | Red Squirrel (1–10) | Nesting Birds (1–10) | Ground Vegetation (1–10) | Recreation (1–10) |
|------------------|----------------|-------------------|--------------------|-------------------|----------------------------------|-------------|---------------------|----------------------|-----------------------|-------------------|
| Initial (2012)   | 902,806        | 4.76              | 3.21               | 2.70              | 4.13                             | 4,566,809   | 2.03                | 6.63                 | 4.30                  | 3.01              |
| Desired          | 1,300,000      | 4.80              | 4.65               | 4.80              | To decrease                      | 13,500,000  | 3.75                | 7.50                 | 5.00                  | To increase        |
| BAU1             | 812,954        | 4.79              | 4.15               | 2.89              | 4.58                             | 5,368,476   | 2.40                | 6.75                 | 4.95                  | 4.05              |
| BAU1Rec          | 801,492        | 4.79              | 4.20               | 2.88              | 4.49                             | 5,544,390   | 2.37                | 6.73                 | 4.96                  | 4.31              |
| BAU1Water        | 804,603        | 4.77              | 4.19               | 2.88              | 3.38                             | 5,531,162   | 2.33                | 6.73                 | 4.97                  | 4.24              |
| BAU1Rec&Water    | 786,310        | 4.76              | 4.25               | 2.88              | 3.37                             | 5,829,555   | 2.44                | 6.72                 | 5.00                  | 4.45              |
| PF2              | 830,278        | 4.98              | 4.27               | 3.59              | 4.58                             | 4,960,456   | 2.30                | 6.99                 | 4.89                  | 4.17              |
| PF2Rec           | 820,511        | 4.97              | 4.37               | 3.57              | 4.31                             | 5,155,016   | 2.29                | 6.97                 | 4.97                  | 4.40              |
| PF2Water         | 806,048        | 4.96              | 4.37               | 3.67              | 3.23                             | 5,345,316   | 2.32                | 6.99                 | 4.94                  | 4.50              |
| PF2Rec&Water     | 826,521        | 4.98              | 4.32               | 3.67              | 3.25                             | 5,100,024   | 2.27                | 7.00                 | 4.90                  | 4.25              |
| PF3              | 805,041        | 4.75              | 4.13               | 2.85              | 4.55                             | 5,445,164   | 2.38                | 6.71                 | 4.94                  | 4.05              |
| PF3Rec           | 793,869        | 4.75              | 4.16               | 2.84              | 4.47                             | 5,578,775   | 2.36                | 6.70                 | 4.96                  | 4.27              |
| PF3Water         | 783,822        | 4.75              | 4.19               | 2.83              | 3.38                             | 5,659,044   | 2.39                | 6.69                 | 4.97                  | 4.32              |
| PF3Rec&Water     | 778,508        | 4.75              | 4.20               | 2.83              | 3.37                             | 5,703,695   | 2.37                | 6.69                 | 4.98                  | 4.38              |
| PF4              | 749,803        | 4.69              | 4.39               | 4.17              | 3.74                             | 5,261,437   | 2.04                | 6.41                 | 5.03                  | 4.53              |
| PF4Rec           | 741,682        | 4.70              | 4.40               | 4.17              | 3.73                             | 5,383,794   | 2.03                | 6.40                 | 5.04                  | 4.67              |
| PF4Water         | 803,414        | 4.68              | 4.25               | 4.30              | 3.42                             | 4,617,958   | 1.92                | 6.50                 | 4.92                  | 4.15              |
| PF4Rec&Water     | 823,573        | 4.73              | 4.26               | 4.50              | 3.45                             | 4,532,851   | 1.85                | 6.48                 | 4.93                  | 4.33              |
| PF5              | 755,407        | 4.77              | 4.44               | 3.77              | 3.72                             | 5,534,104   | 2.22                | 6.56                 | 5.05                  | 4.60              |
| PF5Rec           | 745,253        | 4.78              | 4.44               | 3.73              | 3.70                             | 5,742,926   | 2.21                | 6.55                 | 5.06                  | 4.76              |
| PF5Water         | 801,385        | 4.78              | 4.44               | 3.59              | 3.41                             | 4,884,614   | 2.24                | 6.72                 | 4.92                  | 4.13              |
| PF5Rec&Water     | 819,017        | 4.77              | 4.18               | 3.69              | 3.48                             | 4,725,067   | 2.15                | 6.75                 | 4.89                  | 4.15              |

Note: The 2012 ES outputs and the desired levels, as determined by the stakeholders, are included. In the left column: PF = Potential future; Rec = Public access to all forests backcasting policy; Water = Policy measures implemented to reduce water quality.
3.4.2. Rec and Water in Western Peatland

The higher proportion of CCF management increased the recreation scores when both backcasting policies were applied simultaneously to PFs BAU, 2 and 3. Implementing the two policies in PFs 4 and 5 resulted in a decrease in CCF management, similar to the result of implementing the Water policy on its own, but the Rec policy causes more CCF to remain than when the Water policy was applied by itself. This means that the provision level of recreation was low for PFs 4 and 5 when both backcasting policies were implemented, but not as low as when the Water policy was applied on its own. In terms of timber production, the Rec and Water policies work together in PFs 4 and 5 and resulted in more timber being harvested than in the respective PFs, or when either backcasting policy was applied individually. This higher amount of timber produced resulted from the decrease in CCF management and increase in the proportion of the CSA managed with the traditional approach. For water sedimentation, the risk level associated with implementing both policies was between the risks of the individually applied Rec and Water policies in three of the five PFs. In the remaining two PFs (i.e., 1 and 3) the water sedimentation risk was slightly lower than when the backcasting policies were applied individually. In addition to the Water measures, the retention of stands to increase recreation scores further reduced water sedimentation risk and also increased recreation scores. To accomplish this, in PFs 1 and 3 more land was managed for CCF when both policies were implemented simultaneously than in the original PFs or when either policy was applied individually, resulting in lower timber production than in the respective original PFs.

3.5. Robustness Assessment

3.5.1. Robustness Assessment for Newmarket

The number of PFs (out of a maximum of four) in which the ES provision trend was towards the stakeholders’ desired ES levels through the implementation of the backcasting policies is presented in Table 13. A summary of the number of ESs with provision levels that were either sustained (stayed at the PF level) or that did move towards the stakeholders’ desired endpoints is presented in Table 14. This information is presented for each backcasting policy and PF, and is also totalled per PF.

| Table 13. | The number of PFs (out of a maximum of four) where the average ES provision level (presented in Table 10) stays the same or moves towards the stakeholders’ desired ES level through the implementation of the backcasting policies on the NM CSA. |
|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Ecosystem Service | GI | Rec | GI&Rec |
| Timber | 3 | 1 | 3 |
| Deer cover | 4 | 3 | 3 |
| Deer forage | 4 | 2 | 2 |
| Hen harrier | 3 | 3 | 3 |
| Water sedimentation risk | 3 | 3 | 3 |
| Carbon | 1 | 4 | 4 |
| Red squirrel | 3 | 4 | 4 |
| Nesting birds | 4 | 0 | 0 |
| Ground vegetation | 2 | 4 | 4 |
| Recreation | 3 | 4 | 4 |
| Number of ESs whose provision is improved or sustained in three or more potential futures when backcasting policies are implemented | 8 | 7 | 8 |
Table 14. The number of average ES levels (out of 10, all 10 average ES levels are presented in Table 12) that stay the same or move towards the desired end point, by potential future (PF) and backcasting policy in the NM CSA.

| Backcasting Policy | Scenario |
|--------------------|----------|
|                    | BAU | PF2 | PF3 | PF4 |
| GI                 | 6   | 7   | 8   | 7   |
| Rec                | 8   | 6   | 9   | 5   |
| GI&Rec             | 9   | 6   | 9   | 6   |
| Total              | 23  | 19  | 26  | 18  |

For almost all ESs, there was at least one PF in which the provision level was sustained at the current level or moved closer to the desired level compared to the levels in the original PFs when the backcasting policies were implemented. An exception was the nesting bird ES when the Rec policy was applied. Nesting birds are more attracted to agricultural land and, as the Rec policy encourages afforestation, its ES provision declined for all PFs (Table 13). The result indicated that as the current ES output mix is diverse, the implementation of policies to target some specific ESs resulted in other ESs moving away from their desired ES provision levels. A criterion to indicate the general impact of backcasting policies on ESs was identified: Only if the ES provisions in three or more PFs were sustained or improved was the backcasting policy considered to be beneficial for that ES (even though for full robustness, all four PFs would need to be sustained or improved). The results of this analysis are presented at the bottom of Table 13. The Rec and the GI&Rec (i.e. the GI & Rec policies implemented in the same model run) policies enhanced similar ESs, indicating that the Rec policy was more dominant in terms of satisfying the ESs in the model than the GI backcasting policy. Even though this assessment provided an indication of the trends for all ES provisions as a result of implementing the backcasting policies, some ES provision levels may have decreased (or increase) by an unacceptable amount, which was not accounted for in this assessment.

The policies implemented in PF 3 sustained or moved the provision of the most ESs toward the desired endpoints (Table 14). As there were many attitude changes included in this PF, with forest certification being mandatory and forest policies being more restrictive, management decisions were based on a wider range of ES provisions than in the other PFs. The two PFs with the smallest number of ES levels sustained or improved when backcasting policies were applied on their own or together were PFs 2 and 4. The main difference between these PFs and BAU and PF 3 occurred when the Rec policy was applied. The Rec policy encouraged more afforestation and a more mature age class structure, which does not move the provision of several ESs in the desired direction (i.e., timber production, deer forage, hen harrier and nesting birds). However, the more mature forest resulted in an increase in the sequestered carbon in the forest. Circa 3% less area was managed with the traditional forest management approach (i.e., rotation-based clear-fell system) when the Rec policy was applied to PF 2 or 4, while the decrease was only 1.5% for the BAU scenario and it increased by 1% for PF 3. Even though these proportional changes were small, they represent significant areas as 1% of the NM CSA is approximately 1600 ha.

3.5.2. Robustness Assessment for Western Peatland

A summary of the number of ESs with provision levels that were either sustained (i.e., stayed at the PF level) or that did move towards the stakeholders’ desired levels is presented in Table 15. This information is presented for each backcasting policy and ES, and was also summed per PF in Table 16.
Table 15. The number of PFs (out of a maximum of five) where the average ES level (presented in Table 12) stays the same or moves towards the stakeholders’ desired ES level through the implementation of the backcasting policies in the WP CSA.

| Ecosystem Service            | Rec | Water | Rec&Water |
|------------------------------|-----|-------|-----------|
| Timber                       | 0   | 2     | 2         |
| Deer cover                   | 4   | 2     | 4         |
| Deer forage                  | 5   | 3     | 3         |
| Hen harrier                  | 1   | 2     | 2         |
| Water sedimentation risk     | 5   | 5     | 5         |
| Carbon                       | 5   | 3     | 3         |
| Red squirrel                 | 0   | 3     | 1         |
| Nesting birds                | 0   | 3     | 3         |
| Ground vegetation            | 5   | 3     | 3         |
| Recreation                   | 5   | 3     | 3         |

Number of ESs whose provision is improved or sustained in three or more potential futures when backcasting policies are implemented: 6 7 7

Table 16. The number of average ES levels (out of 10, all 10 average ES levels are presented in Table 12) that stay the same or move towards the desired end point, by potential future (PF) and backcasting policy in the WP CSA.

| Backcasting Policy | BAU | PF2 | PF3 | PF4 | PF5 |
|--------------------|-----|-----|-----|-----|-----|
| Rec                | 6   | 5   | 6   | 7   | 6   |
| Water              | 5   | 8   | 7   | 4   | 5   |
| Rec&Water          | 6   | 8   | 6   | 5   | 4   |
| Total              | 17  | 21  | 19  | 16  | 15  |

Across the five PFs, whether the backcasting policies were applied individually or simultaneously, they sustained or enhanced a similar amount of ESs in total (i.e., 30 for the Rec policy and 29 each for the Water and Rec&Water (i.e. the Rec and Water policies implemented in the same model run) policies on their own). The Rec policy resulted in the creation of more mature and more broadleaf stands, which enhanced certain ES provisions for a majority of PFs while reducing the provision of other ESs. The Water policy was more effective as it generally enhanced the provision of a wider range of ESs when applied to the PFs.

When the number of ESs whose provisions were sustained or moved in the stakeholders’ desired direction are categorised by PF, PFs 4 and 5 provided fewer desirable changes in ES provision when the Water backcasting policy was applied compared to the Rec backcasting policy (Table 15). The Water backcasting policy was heavily focused on enhancing the provision of two ESs (i.e., increased timber production and reduced water sedimentation risk). The provision of these two ESs can be achieved through harvesting and restoring forested land to bog in PFs 4 and 5. The bog land-use had very good values for some ESs (e.g., hen harrier and low water sedimentation risk); however, for others it is poor (e.g., red squirrel and timber production) and, hence, the lower number of ESs moved toward the desired end point.

3.5.3. National Level Stakeholder Involvement

The National level stakeholder’s opinion of the backcasting policies was generally positive, stating that the implementation of the policy measures is feasible within the overall Irish policy context. However, they suggested that a more targeted and limited level of implementation would be more appropriate. For instance, they indicated that the cost required to compensate land owners for public access compared with the benefits of the Rec policy would not make it attractive on a nation-wide basis, but that such a policy should be much more targeted towards forests near population centres.
or in parts of the country where few recreational forests exist. They also stated that the recreational value of a forest can change with time as the public perceive the forests as less of a novelty over time. Therefore, the subsidy should only be provided for a limited time to any particular forest owner after which their forests need to be reassessed.

When the Water backcasting policy was discussed, the national level stakeholders indicated that they were investigating dynamic buffer zone widths. Rather than set widths within a policy designated zone, the buffer zones would be determined dynamically depending on the relative risk of each particular site to negatively affect water quality. For example, increasing widths of buffer zones near watercourse confluence points and on steep sites, and possibly reducing widths of buffer zones in areas which are less likely to contribute towards increasing risk to water quality.

The overall feedback was that the three backcasting policies investigated were too drastic compared to what would be practically implementable. The authors have verified that the suggested refinements that the national stakeholders outlined to make these backcasting policies more implementable would result in trends in ES provision levels in the same direction, but not as pronounced as the backcasting results presented.

4. Discussion

Goal programming was shown to be a good and flexible modelling method in this study. This was the general consensus from the informal feedback sessions held with the local level stakeholders after each CSA backcasting workshop. Participants appreciated the transparent nature of the modelling process and the lack of a “black box” approach. GP allowed for multiple ESs to be modelled in a dynamic and interactive fashion, demonstrating to the stakeholders the effects of emphasising one or more ESs over others. The simple structure of the GP model (i.e., clear policies that were applied over the entire CSA) made it straightforward to explain to the stakeholders the underlying assumptions, which facilitated the acceptance of the model output by them. It also made it possible to demonstrate the limits on what the case study areas could deliver so that unrealistic expectations could be eliminated. Of course, GP has previously been used frequently for multi-criteria decision making [52] and is particularly useful towards assessing multiple ESs. However, the use of GP in the context of backcasting is novel and the authors were unable to find similar published research methods and findings. A remaining question that is often associated with GP applications is how to set the goal levels [53]. If appropriate goal levels are unclear, perhaps fuzzy goal programming could be used to determine goal levels [54,55]. Diaz-Balteiro et al. [56] used pairwise comparison matrices in the analytical hierarchical process (AHP) to include the preferences of several stakeholders within the GP models that optimise forest management in two forests in Spain. Aldea et al. [57] used participatory goal programming and showed how inputs from stakeholders are essential to select the proper GP model as well as some of its components, such as targets and preferential weights. For applications that are focused on a narrower range of ESs where individuals have considerable knowledge of how the ES is quantified, the use of an expert panel can be considered [58]. An advantage of the GP modelling approach is that the effect of enhancing the provision of some ESs on other ESs can be evaluated. For example, the Rec backcasting policy does have the desired effect on the provision of recreation in all PFs in both CSAs. However, the question is whether the reduction in timber production in eight of the nine PFs (from both CSAs) resulting from the implementation of the Rec policy is acceptable to all stakeholders in an industry which is experiencing an increasing demand for timber. The GP model provides the quantitative information to evaluate such trade-offs, resulting in more refined and targeted policies that are supported by all local stakeholders. However, the national level validation is also important as this is the level at which potential conflicts with existing and between proposed policies at the national and international levels should be identified and addressed.

Combining the project team’s expertise of the modelling system developed with the participatory workshops was useful in selecting potentially robust backcasting policies. When a backcasting policy was suggested, a qualitative analysis of its effect on the targeted and other ES(s) was carried out. This
provided the local stakeholders with real-time information on how their proposed policies would most likely influence ES provisions in a range of PFs. In many cases this led to refinement of the stakeholder proposed backcasting policy. This qualitative validation process was the first step towards ensuring that the backcasting policies assessed for robustness would positively affect the targeted ES provisions. This was followed by the quantitative GP modelling process. In further studies, a method to quantitatively indicate the level of trade-offs during the local stakeholder workshops would be beneficial and the Pareto Frontier method presented by Borges et al. [59] could serve this purpose. Borges et al. [60] presented a multicriteria approach for the negotiation of supply targets for ESs and forest owners’ support programmes. Capturing the forest owner structure and behaviour is also an important aspect of landscape level modelling [61,62], and this has become one of the focus areas of decision support system development in recent years [63,64]. In this study, owner behaviour was included in the models, for instance in their response (i.e., attitude change) to the introduction of recreational incentives. However, further research is required to capture the differences in owner types in relation to their choice of management approaches, especially under changing market and climate change conditions.

The GP method has an inherent limitation for the type of backcasting application used in this study, similar to the spatial constraints limitation outlined in Corrigan and Nieuwenhuis [49]. Some potential backcasting policies suggested by the local stakeholder group, although being particularly innovative, could not be investigated. The implemented GP models were already at the limit of acceptable solution times and available computing resources, due to the combinatorial “explosion” of potential options. This meant that regulating the size of felling coupes (also a requirement for forest certification) and other spatial related modelling options were not implementable. To address this in future studies, a heuristic tool in Remsoft’s Spatial Planning Suite, known as the Spatial Optimiser, could be used. It uses a binary search method and has been designed to incorporate the relative spatial positioning of land-use parcels within its algorithm. This would allow for a more refined assessment of ESs by evaluating the spatial patterns required (e.g., for habitat and recreation provision). Such spatially explicit solutions would also be easier to assess by stakeholders and have the potential to be directly implementable in practice.

This study evaluated policies, determined by local level stakeholders, which were expected to provide a more desirable mix of ESs. The results of the robustness assessment indicate that the backcasting policies achieved their intended objective of increasing the provision of the targeted ESs for seven out of ten ESs in the NM CSA and six out of ten ESs in the WP. This can be considered a moderately successful outcome. However, it would be unrealistic to expect that there will not be trade-offs between some ESs and the ESs targeted by the backcasting policies (i.e., timber, water sedimentation risk and recreation) [26,65]. The desired provision levels have also been more closely approached in some PFs compared to in others, indicating that some PFs put more constraints on the ESs irrespective of the backcasting policy. The silvicultural treatments used can also have an important effect on the ESs delivered in a landscape [66]. The introduction of additional, alternative forest management approaches could help in eliminating some of the ES trade-offs.

The national level stakeholders, who assessed the backcasting policies, indicated that changes should be made to these policies before they would be implementable. It is strongly recommended that the implementable backcasting policies are discussed with the local level stakeholders and, if agreed by them, that they are reassessed using the backcasting model developed in this study. The approach described by De Bruin et al. [24] fits in with the Dutch government’s shifted focus towards policy approaches that include social engagement and support and the authors recommend using it as an addition to current predictive approaches. The authors of the Irish study presented in this paper strongly support this recommendation based on the evidence and results obtained and the feedback provided by the stakeholders that participated.
5. Conclusions

The modelling framework for evaluating policies determined from backcasting outlined appears to be a good approach. The use of GP seems to be a good fit, particularly for its flexibility to accommodate the very apparent multiple objectives of local level stakeholders in Ireland. Being able to quantify multiple ES simultaneously is essential for a true evaluation of a backcasting policy, as it allows for the positive and negative effects to be assessed, as metrics, as opposed to qualitative discussions. The modelling results directly showed if the backcasting policies achieved their desired intention for the targeted ES (i.e., GI improved the quantity of timber produced, Rec improved the recreation score and Water reduced the risk of water sedimentation). Furthermore, implementing two policies in one model run highlights that the backcasting policies assessed are fit to be implemented together, as they moved ES provision in the desired direction for most cases. This was supported by the robustness assessment, indicating that the backcasting policies modelled do achieve the desired intention for the wider selection of ES in this study also. The robustness assessment was particularly useful for the discussion with the national level stakeholder group. They felt they had enough information to outline the potential of implementing each backcasting policy in practice. GP has a place in a framework for analysing backcasting policies and, also perhaps, as part of a wider scope of policy related ecosystem service assessments. This is evidenced by continued use of this modelling platform in the ALTERFOR project [67].

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Appendix A

Table A1. Stakeholder groups involved in the Western Peatland interviews/workshops and their interests. Source: Bonsu, Dhubhain and O’Connor [47].

| Stakeholder Groups                      | Stage 1: Interviews | Stage 2: Workshop | Stage 3: Workshop 2 | Key Interests/Stakeholders                                                                 |
|-----------------------------------------|---------------------|-------------------|---------------------|-------------------------------------------------------------------------------------------|
| **Primary Stakeholders**                |                     |                   |                     |                                                                                           |
| Farmer Forest Owners                    | √√√√                | √                 | –                   | Premium payments/money; timber and non-timber production e.g., wood fuel/biomass           |
| Private Forest Owner/Investor           | √                   | √                 | √                   | Premium payments/money; timber and non-timber production e.g., wood fuel/biomass.         |
| Public Forest Company/Coillte           | √                   | √                 | √                   | Commercial timber production, financial benefits from land management, bioenergy development, forest recreation and biodiversity protection. |
### Table A1. Cont.

| Stakeholder Groups | Stage 1: Interviews | Stage 2: Workshop | Stage 3: Workshop 2 | Key Interests/Stakeholder Groups |
|--------------------|---------------------|-------------------|-------------------|----------------------------------|
| **Secondary Stakeholders** |                      |                   |                   |                                  |
| National Forest Authority (Forest Service) | ✓ | ✓ | ✓ | Responsible for implementing national forest policies and ensuring SFM practices |
| National Parks and Wildlife (NPWS) | ✓ | - | - | Biodiversity conservation |
| Inland Fisheries Ireland | ✓ | ✓ | ✓ | Water resource and catchment protection |
| Non-Governmental Organisation/Local Community representative | ✓ | ✓ | ✓ | Forest contribution to rural development/jobs |
| Sawmill Industry | - | ✓ | - | Timber supply |
| Environmental Protection Agency | - | - | ✓ | Statutory body for the balanced and sustainable protection and management of the environment |
| **Tertiary Stakeholders** |                      |                   |                   |                                  |
| Local County Council and Recreational Groups | ✓ | ✓ | - | Tourism development, hiking and walking |
| Scientists and Ecologists | ✓ | - | - | Forest research and development |
| Teagasc | ✓ | ✓ | ✓ | Rural development and farm forestry advisory/training |
| Biomass Industries | - | ✓ | ✓ | Biomass as a source of energy |
| Deer Hunters | ✓ | - | ✓ | Deer hunting |
| Sea Angler/Fishermen | ✓ | - | - | Fishing for recreational purposes |
| Number of Stakeholders' Involved | 14 | 11 | 8 |                                  |

✓: Number(s) of stakeholders interviewed and/or participated in workshop; −: Interests represented by other stakeholder groups.

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