Science framework for assessing new mitigation activities for natural carbon sequestration

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Project and client

Manaaki Whenua – Landcare Research, a group of the Bioeconomy Science Institute, has been commissioned by the Ministry for the Environment (MfE) to summarise the underlying scientific principles for evaluating carbon sequestration activities using natural climate solutions.

Background

- High-quality carbon sequestration and greenhouse gas emissions reductions are crucial components of global climate change mitigation strategies, but the scientific principles to evaluate the suitability of including new activities towards meeting targets and expand the coverage of New Zealand's Nationally Determined Contributions (NDC) have not been collated.
- The IPCC has emphasised the critical global need for mitigation strategies in the Agriculture, Forestry and Other Land Use (AFOLU) sector to achieve net zero emissions through reducing greenhouse gas emissions and storing carbon. These measures are also called natural climate solutions.
- Defensible criteria for assessing the validity of proposed new carbon sequestration activities are required to guide decision-makers both inside and outside central government, to enable a wider range of activities to contribute toward meeting our climate goals.

Methods

We reviewed the published literature and technical documents to identify the key scientific principles underpinning natural climate solutions.

Results and discussion

- We developed a two-stage science assessment framework that aims to assess 'readiness' (demonstrable potential) and 'sufficiency' (practical implementation) for inclusion in the NDC or voluntary carbon markets.
- The key principles for science readiness include measurable, validated, additional, and permanent. For science sufficiency the principles include material, scalable, leakage, transparent, and sustainable. For each of these principles we provide a working definition, a brief rationale for inclusion in the framework, and guidance for their application or implementation.
- Principles in the science assessment framework developed here are treated as normative criteria for guiding decisions about the quality and confidence of the evidence for the carbon sequestration from a proposed activity.
- Decisions based on principles require a system for evaluating confidence in the evidence used across disparate sources of data, knowledge or insights.

Recommendations

- The readiness principles of measurable and additional are essential for determining the unique and measurable effect of proposed activity on C: a proponent of a sequestration approach must demonstrate that carbon gains or removals can be attributed to management or some other intervention that is not business-as-usual. Additional research or evidence needed to improve confidence that the proposed activity meets these principles should be identified using the science assessment framework.
- In many cases involving innovative or novel approaches, forecasting or counterfactual models should be considered as evidence. This requires expertise to interpret the robustness and strength of predictions, and transparency about the assumptions and analysis.
- Guidance on transparency and strength of evidence is required, both for proponents and for decision-makers. We suggest adopting the IPBES[1] (2018) framework for this initially, because it is simple and well established, and will work across the different principles and diverse data or evidence used by proponents.
- Using scientific principles as criteria in decision-making will require either clear instructions for how criteria are to be evaluated for proponents of the activities, or expert guidance from government or highly qualified personnel.
- Just how this natural carbon sequestration science framework is embedded within decisions about inclusion in the NDC or other carbon accounting systems needs to be considered. A user-friendly summary and guidance for decision-makers would help to identify the relative scientific strengths or merits of proposals. This could include FAQs or using the science framework as a basis for initial questions about inclusion in the NDC or other schemes by proponents.
- Many natural climate solutions activities are motivated by co-benefits such as biodiversity, environmental and socioeconomic indicators, alongside carbon sequestration.

[1] Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

1 Introduction

1.1 General context

High-quality carbon sequestration and greenhouse gas (GHG) emission reductions are crucial components of global climate change mitigation strategies. The urgency and need for wider mitigation activities are clearly stated in repeated Intergovernmental Panel on Climate Change (IPCC) assessments and global consensus (e.g. Fawzy et al. 2020; Ripple et al. 2020; Masson-Delmotte et al. 2022). The required scale of the activities is staggering: the latest IPCC assessments suggest that about 6 Gt of carbon dioxide removal per year is needed by 2050 to limit global warming to 1.5°C, and more is needed if emissions reduction targets are not met (IPCC 2022). As a consequence, increasing GHG removals and carbon sequestration are essential for meeting international climate goals or commitments such as the Paris Agreement (UNFCCC 2015; Schleussner et al. 2016). Carbon sequestration, the process by which CO_2 from the atmosphere is transferred and accumulates in reservoirs such as soil and plants, thus crucially links current emission trajectories and long-term climate goals.

The IPCC has emphasised a global need for rapid implementation of mitigation measures within the Agriculture, Forestry and Other Land Use (AFOLU) sector. This is needed to limit global temperature rise to < 2°C by providing substitutes for fossil fuels and removing carbon dioxide from the atmosphere (IPCC 2022). These measures are also called natural climate solutions (NCS). NCS are deliberate human actions that protect, restore, and improve the management of ecosystems to mitigate climate change without harming biodiversity or well-being, and they could deliver a third of the climate mitigation needed by 2030 (Griscom et al. 2017). NCS have the potential to provide effective, durable solutions to climate change mitigation, allowing for both carbon capture and reduced emissions (e.g. through restoration of peatlands; see example in section 6.3). Nature-based climate solutions (NbCS) that manipulate one or more components of ecosystems to reduce emissions, protect existing sinks, or increase carbon sequestration are a subset of the general NCS.

NCS are a crucial component of Nationally Determined Contributions (NDC).[2] These are commitments that countries make to reduce their GHG emissions or increase carbon sequestration as part of climate change mitigation to achieve global targets over specific time periods, as set out in the Paris Agreement (UNFCCC 2015). The inclusion of new activities or improvements to emissions estimates for tracking emissions reduction targets set through NDCs require consistency with IPCC guidance for national GHG inventories, and be based on scientifically robust evidence.

High-quality carbon sequestration is widely supported as a durable solution to climate change mitigation. The quality of carbon sequestration is widely thought to be linked to its permanence (i.e. the duration for which CO_2 is removed from the atmosphere), additionality (i.e. removals above the status quo), and verifiability (i.e. in part, robust measurement). This is consistent with Climate Change Commission (2024) advice on national emissions reporting, which recommends adopting the principles of additionality and permanence (durability), and including these as criteria for any

[2] https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs

recognised carbon removal activities, alongside removal capacity, measurability, cost, and acceptability.

1.2 Developing high-quality NCS mitigation activities

Credible, evidence-based NCS carbon sequestration activities depend on establishing causal relationships between new management activities or interventions and measurable, high-quality carbon sequestration (e.g. Fargione et al. 2018). Credibility relies on scientific substantiation of carbon gains from a management activity, including quantitative verification and analysis (Novick et al. 2022, 2024). The scientific basis and principles for assessing the potential of new mitigation activities or interventions for carbon sequestration are required as part of broader efforts to strengthen NDC and meet international climate mitigation goals.

A first step towards understanding whether a new activity (i.e. new management or intervention beyond the *status quo*) could contribute to our NDC is to determine the scientific robustness of its carbon sequestration. Standards are available for estimating and reporting greenhouse gas emissions for all sectors of the economy (IPCC 2006; IPCC, 2019). The methods used in the estimation of greenhouse gas emissions reported in national greenhouse gas inventories are subject to biennial technical expert review. There are however no agreed standards for assessing the scientific robustness that underpins new emissions sources or sinks, or the impact of some management actions, that are not currently provided by the IPCC. Some countries have developed country-specific assessment standards for the inclusion of novel emissions sources or sinks in their NDC (e.g. Australia), some voluntary carbon market (VCM) standards (e.g. the Verified Carbon Standard administered by Verra) for GHG accounting (see section 6 below), and in the literature for NCS (e.g. Ellis et al. 2024).

Here we consider the underlying science or evidence-based principles that could be used to verify whether new management activities or interventions are supported by sufficient scientific evidence that the activities will result in high-quality carbon sequestration. Carbon sequestration outcomes refer to the long-term removal of CO_2 from the atmosphere , so a high-quality carbon sequestration outcome should increase the content of a carbon pool by management practices (Don et al. 2024). For example, restoration of a degraded peatland might increase carbon sequestration (and thus removals of carbon from the atmosphere). For any management intervention there is clear guidance that NCS do not include avoided carbon losses; for example, by claiming avoided deforestation or harvest (e.g. Griscom et al. 2017; Seddon et al. 2020, 2021). High-quality carbon sequestration or long-term 'removal and storage of carbon' imply management that ensures the carbon removed is not simply re-emitted at some point in the future.

We outline requirements to robustly verify whether sequestration has indeed occurred following interventions. Although policy is also required to guide high-quality carbon gains, this report focuses on the scientific basis of claims for new activities or interventions. We take an ecosystems view, which is consistent with the biophysical interpretation taken by NDC, rather than a GHG reporting, market or policy interpretation.

Ultimately, this work develops a framework for assessing the scientific merit or 'readiness' of a new activity for inclusion in national reporting and accounting or smaller-scale VCMs. An overall goal of this report is to clearly communicate the scientific principles, or normative criteria, that could be used by a proponent, MfE science staff, or independent assessors to evaluate the merit of a proposed activity for enhancing carbon sequestration.

Summary: There is a rapidly growing need and literature for addressing the climate crisis internationally by supporting new innovations or methods to remove GHGs or sequester carbon, and to robustly report on progress at a national scale.

2 Objective

Our objective is to develop a science-based framework that summarises the underlying scientific principles for high-quality carbon sequestration in new NCS activities. We do this by proposing a framework based on the published literature and evaluated against requirements of accounting for national-level emission reduction targets or VCMs. This framework could be used as input or advice for MfE to use in its development of policy and guidelines for how to assess the scientific rigour of proposed new carbon sequestration activities.

3 Desired science frameworks

To be considered for inclusion New Zealand's NDC, the emissions impact of any mitigation activity must be reported in New Zealand's GHG Inventory and in this respect must adhere to IPCC guidelines (MfE 2025a). The science framework proposed here provides support for understanding the burden of proof required by a reporting country to adhere to the IPCC guidelines, or for cases where existing IPCC guidance is limited or lacking. The science framework developed here guides MfE and proponents of mitigating activities to meet this burden of proof required by a reporting country where existing IPCC guidance is limited or lacking. The science framework developed here guides MfE and proponents of mitigating activities to develop this burden of proof and define what evidence is required for decisions about inclusion in the GHG inventory and the NDC. If the goal is to contribute to the NDC, then measurements supporting the framework must be consistent with international GHG inventory reporting guidelines (UNFCCC 2018; IPCC 2006). These guidelines consider robustness of evidence and the full time series back to 1990.

Because the framework deals with new mitigation activities that are sometimes little tested, a two-stage, natural carbon sequestration science-based framework is recommended that utlises the principles summarised below (section 6).

3.1 Stage one: science readiness

The first stage of the framework evaluates *science readiness*. This is an initial assessment of a proposed activity to confirm that current scientific evidence supports further investigation of the activity. Inputs needed to evaluate readiness could include specification of the scope and scale of the activity planned, the research and data availability, or international examples applied locally. It could also include consideration of the scale of counterfactual research indicating that no, or minimal, carbon sequestration would occur without the addition of human activity. This is because New Zealand has opted to account only for the net gain in carbon sequestered intentionally through human activities that have occurred since 1990 (so natural CO_2 emissions and removals from forests that existed before 1990 and that would have occurred anyway are excluded).

Key elements for science readiness include resolving the following questions.

- Is there a *prima facie* case (based on the peer-reviewed literature or other reputable source) that the proposed human-induced activity removes CO_2 from the atmosphere?
- What is the evidence, at the outset, that management effects from the project's start date demonstrate a material change that is discernible from a baseline, especially if that baseline is non-zero?

3.2 Stage two: science sufficiency

The second stage of the framework evaluates *science sufficiency*. This is an assessment of whether the available science, models, and data gathering methods are available to implement either a national-scale monitoring approach (i.e. for inclusion in NDC accounting), or potential inclusion in voluntary markets. The scale of research and data required is likely to be greater for NDC inclusion (which is national) than for inclusion in voluntary markets (which could be smaller scale), but which generally still pass through a registry to avoid double-counting. For a new activity to be counted towards the NDC, emissions estimates must be reported in the GHG inventory in accordance with their requirements (MfE 2025).

Key elements for science sufficiency include resolving the following questions.

- How will the strength of the mitigation effect or activity on a potential net sink be determined and uncertainty evaluated? Are approved or validated methods provided to quantify/estimate changes and uncertainty in all relevant carbon pools (e.g. live biomass, dead organic matter, and soil carbon)? Are methods provided to estimate non-CO_2 GHG emissions (e.g. methane from anaerobic decomposition of organic material in wetlands)?
- What is the confidence (give the bounds of uncertainty) in the longevity/permanence of the effect?
- What form of measurement and monitoring will be used, and at what periodicity?
- How will leakage or unintended consequences be prevented (e.g. shifting the potentially negative effect of the project somewhere else)?

3.3 The science framework and the greenhouse gas inventory

The science framework is a structured approach to undertaking evidence-based assessments for determining the robustness of new mitigation activities. Activities that demonstrate scientific robustness could then be progressed to further steps and opportunities (Figure 1). In addition, the framework provides a list of principles, as well as the types of data and/or evidence needed for each principle, for an assessment using the framework (see section 6). This allows determination of whether the activity meets the requirements of scientific readiness and sufficiency (Figure 1). Users can check off whether evidence is provided for each of the principles in the science assessment. Finally, the framework can be applied to score the quality of the scientific robustness of proposals.

For a new removal activity to be considered for inclusion in New Zealand's NDC it must also be part of New Zealand's national GHG Inventory, which adheres to IPCC guidelines (MfE 2025a). However, where IPCC methodology is limited or lacking, the science framework developed in this report provides support for the burden of proof required. The science framework developed here could guide MfE and proponents to develop this burden of proof and indicate the evidence required for decisions about the inclusion of activities in the GHG inventory and the NDC.

We note the following standard requirements for updating the inventory (these will also be required by default if the goal is to contribute the apportionment towards the NDC). The proposed update must be:

- in line with and adhere to IPCC guidelines for international GHG inventory reporting (IPCC 2006 guidelines are mandatory; other IPCC guidelines are voluntary)
- based on scientifically robust evidence
- unbiased and nationally representative
- more accurate than reported previously
- cover the full time series back to 1990.

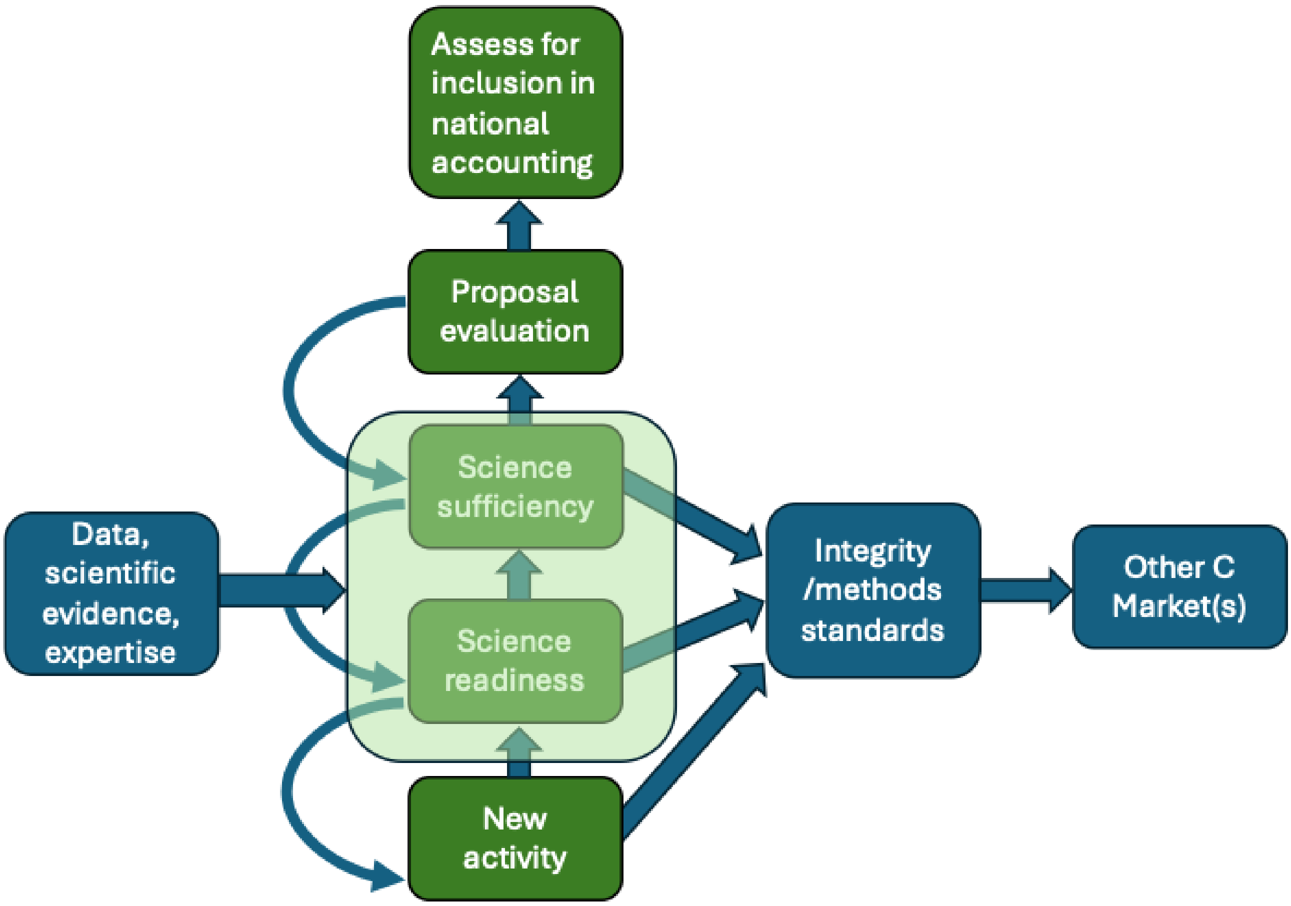

Figure 1. Illustration of information flows (arrows) for new proposed mitigation (removal) activities for NCS that require sufficient information to pass science readiness and sufficiency parts of the framework, before wider proposal evaluation and adoption within the NDC. Curved arrows indicate where additional information or evidence is required before proceeding.
Note: Alternative markets could also be considered that include additional standards or evaluation before inclusion.

Summary: Our goal is to develop a two-stage framework that first outlines the science readiness (stage one) and then the sufficiency (stage two) requirements, derived primarily from the published literature. The outputs from this work are intended to enable assessment of the scientific robustness of new activities or interventions (natural climate solutions) that could contribute to meeting New Zealand's emissions reduction goals.

4 Literature interrogation

We used several approaches to rapidly identify the common science principles.

- A Web of Science search of peer-reviewed publications using the query 'scientific principles of natural climate solutions'[3] returned 323 records, including 7 highly cited papers and 74 review publications (as at 26 May 2025). We evaluated the highly cited papers and the most recent (2023–2025) reviews. Most (over 90%) of the records were considered not relevant for this project because they either reported site-specific results, addressed engineering or technological solutions, or reported primarily on policy, economics or other topics considered outside of scope for this project.
- A Google Scholar query 'scientific principles of natural climate solutions' was used, restricting records to the past decade (2015–2025) and sorted by relevance, with the top 40 papers evaluated for appropriateness and contribution to the science framework (from about 17,900 records identified by Google Scholar, as at 26 May 2025).
- A distillation of recent literature used the queries 'What are the scientific principles underlying natural climate solutions?' in SciSpace (https://scispace.com) and 'scientific (principles or evidence or data) needed for claiming carbon credits for nature based solutions' in Perplexity (academic deep research mode). SciSpace and Perplexity are AI-tools that summarise content from peer-reviewed publications. They are not a replacement for critical evaluation of the literature, but they are a rapid approach for deriving key elements or themes from the published literature.
- A selective query was conducted on scientific principles applied internationally, including Australia (land sector mitigation activities and coastal wetland restoration), UNFAO[4] and UNDP[5] guidance for land sector mitigation actions in NDC.

These initial approaches identified many of the same publications, suggesting there are relatively few recent, influential (i.e. highly cited) documents directly on the principles or concepts underpinning NCS or broader carbon sequestration claims, despite hundreds of additional papers that report on specific aspects of this broad topic. We did not undertake a systematic review of the literature given the broad range of topics covered for NCS and associated topics.

In addition, search engines such as Web of Science, Google Scholar, and SciSpace do not discover many past publications that may be relevant (there is a bias towards recent documents), nor do

[3] https://www.webofscience.com/wos/woscc/summary/821e778a-ac7b-4971-85fe-77c4bc10e5c2-0164759dcb/relevance/1

[4] Food and Agriculture Organization of the United Nations.

[5] United Nations Development Programme.

they identify relevant 'grey literature', including contract reports, methods or protocols posted online, or policy documents. We applied our experience and expert knowledge of key previous, peer-reviewed publications, including both journal articles and contract reports, to refine the principles evaluated for inclusion in the scientific framework. Finally, we highlighted the principal application or issues using selected case studies or exemplars, drawn from the literature (see section 7).

Summary: Multiple search techniques were used to distil the vast and growing literature on NCS and carbon sequestration to identify a subset of the literature most relevant for defining the principles needed for the science readiness and sufficiency stages of the framework.

5 Summary of findings

Key findings from the literature synthesis for identifying science principles for high-quality carbon sequestration in new mitigation activities are summarised below.

- There has been a rapidly growing literature on NCS and its definition over the past decade, with debate over the urgent need for, deployment of, and use of NSC (beginning with Griscom et al. 2017). In addition, there is active debate about what constitutes 'acceptable' carbon sequestration, broadly including considerations of carbon gained or emissions lowered, but also the consequences for biodiversity and livelihoods. Overall, 'legitimate carbon sequestration' is sought after and actively debated, but there are no universal standards in place (but see IPCC GHG inventory, IPCC2022).
- There is both confusion and potential controversy over terminology and implementation across the science–policy–implementation interface. In part this is driven by the breadth of the scales, both biophysical and socio-political, addressed in the literature. Publications include a mixture of those evaluating the conditions and effectiveness of international agreements, national reporting or monitoring, and the effectiveness of regional or local activities.
- The recent global analysis of Ellis et al. (2024) is the most comprehensive, compelling review of principles for NCS to date. This paper is a timely, highly cited distillation of principles, and is the most relevant publication for this project.
- Here we define principles as the scientific criteria used to guide decisions about the quality, effectiveness, and viability of NSC.
- There is active research on and uncertainties about carbon cycling and its measurement. As an example, the definition of 'permanent' ranges from a few decades to over 100 years and rarely considers the long-term nutrient dynamics of systems that regulate the capacity of ecosystems to sequester carbon.

Overall, we provide sufficient detail on the literature interrogation terms and methods used so that this assessment can be updated as required.

For completeness, we also considered the more generic accounting principles developed for GHG reporting. Clearly defined principles by the IPCC (2006) have been broadly adopted, along with more recently derived principles of relevance and conservativeness (see Olsen et al. 2018; Gillenwater 2022; UNFCCC A6.4-STAN-AC-003)[6]. Briefly, these principles include:

- transparency: sufficient and clear documentation for inventory compilation and reporting
- completeness: estimates are reported for all relevant categories of sources and sinks, and gases
- consistency: estimates of GHGs over time reflect real differences in emissions or removals rather than a change in methods
- comparability: reporting of GHG inventories allows comparison with other countries
- accuracy: both over- and underestimates of GHG inventories are avoided by removing known biases.

These are data quality principles used to ensure robust GHG reporting in national inventories or projects rather than scientific principles.

6 Principles of natural climate solutions

The rapid increase in interest in and potential activities for NCS have created some confusion and controversy. The pursuit of NCS can lead to well-intentioned but hastily and poorly designed programmes, which has led to criticism about their underlying logic and implementation (Fleishman et al. 2021), or worse, deliberate exploitation. There is a need to ensure the integrity of NCS deployed with the intention of removing CO_2 from the atmosphere. For NCS to be scaled up, defensible, robust principles or normative criteria are essential for guiding practitioners, policymakers, and researchers to evaluate whether NCS are viable, tangible, and appropriate. Ellis et al. (2024) identified five foundational principles of NCS (nature-based, sustainable, additional, measurable, and equitable) and 15 operational principles for practical implementation (Figure 2).

[6] UNFCCC. A6.4-STAN-AC-003. Standard: Article 6.4 validation and verification standard for projects. Version 02.0. https://unfccc.int/sites/default/files/resource/A6.4-STAN-AC-003.pdf

Figure 2. Summary of foundational principles (outer labels) and operational principles (inner segments) identified by Ellis et al. (2024).
Note: Here principles are defined as normative criteria to guide decisions about the viability and appropriateness of a solution.

We adopt Ellis et al.'s (2024) definition of principles as normative criteria used to help evaluate the quality of proposed activities or interventions, and to guide decisions about their practical use and adoption. The principles of *measurable* and *additional* (including durable) *sensu* Ellis et al. (2024) are crucial elements we consider further below in developing the science framework. The principle of *nature-based* climate solutions (NbCS) are evaluated further, but the science framework is not restricted soley to NbCS. The principles of *equitable* and *sustainable* are essential for determining the overall acceptability and implementation of an activity, but they are beyond the scope of scientific assessment and should be considered later in policy and implementation. Ellis et al. (2024) do not consider the mandatory IPCC requirements for GHG inventory reporting (see section 5), so their summary only partially shapes the science framework developed here.

6.1 Science readiness principles

Four principles have been identified for the science readiness part of the framework based on the literature search. If a project activity or intervention is able to meet these principles to some level of quality or certainty (see section 7), then the second part of the framework (science sufficiency) would be applied. For readiness principles we mainly consider NCS, although other solutions are not excluded from consideration. For example, activities that intervene in biogeochemical cycles to increase carbon sequestration or permanence, such as geoengineering of silica in soils, could be within scope (e.g. Almaraz et al. 2022).

For each principle we provide a working *definition*, a brief *rationale* for inclusion in the framework, and its *application* or implementation.

6.1.1 Measurable

Definition: The overall magnitude can be quantified (in terms of the amount of CO_2 equivalents removed from the atmosphere) and considered only when sufficient, statistically significant evidence supports inclusion. Measurability is determined if the data and methods used to quantify a change in one or more carbon pools are available to quantify the impact of the activity on GHG fluxes. This may be against a zero or non-zero baseline. Measurability is satisfied when the data and methods used can robustly quantify a change in one or more carbon pools.

Rationale: At the most fundamental level, if the effect of a proposed activity does not result in a quantifiable change in one or more carbon pools or GHG fluxes it cannot be considered further (Gifford 2020; Buma et al. 2024). This principle does not require which major carbon pool is to change; rather, a change could occur in one or more of the major carbon pools, such as aboveground biomass, belowground biomass (or substrate for aquatic systems), dead organic matter, soil or sediment organic carbon, or, for the aquatic environment, dissolved and particulate carbon. Many methods are already available to estimate emissions and removals from these carbon pools, and demonstrating which methods alone or in combination could measure the effects of a new activity above baseline is critical.

Application: The measurable principle could be demonstrated with a wide range of current methods, innovative approaches or new technologies. What is clear from the literature is the high variability and sometimes small effect size of management activities or interventions on carbon in ecosystems. For example, the effects of grazing animals on vegetation or soil carbon is typically <2% of total ecosystem carbon and requires more than a decade to detect with plot-based methods or in models (Tanentzap & Coomes 2012), although new techniques such as isotope tracing and microbial changes in function could measure shorter-term responses. Similarly, advances in GHG measurement such as eddy covariance flux towers can generate high-resolution measurements but over relatively wide spatial areas, which may or may not be able to distinguish the specific effects of a management intervention.

Measurable is a broad principle that includes many elements of sampling, measurement, and interpretation. Relevant elements of sampling design are similar to those used for determining biodiversity responses to invasive species management, and include defining the sampling universe, specifying treatments, having sufficient replication, representative sampling, determining initial conditions, accounting for the effects of implementation, and avoiding observer/analyst bias

(Allen, Forsyth et al. 2023). These design elements are also relevant to evaluating the quality of evidence and measurement of carbon. They can account for common considerations in experimental design, such as the sampling effort required, the frequency and duration of data collection, replication, and the suitability of data for subsequent analyses and interpretation.

Although few studies in New Zealand have the resources to adopt all these elements of design (most likely due to logistical or practical constraints), the more that are adopted the greater the quality of evidence (Allen, Forsyth et al. 2023). Good design ensures data are collected in a robust way, and at a scale and frequency to test a hypothesis or outcome with some level of confidence. Moreover, the quality of measurement and data underpin other principles below, such as causality and quantifying additionality. Quantitative analyses (e.g. power analyses) would provide the strongest evidence for the data available or collected to detect changes in carbon given expectations of *scalability*, *permanence*, and *materiality* (e.g. Holdaway et al. 2012).

6.1.2 Validated

Definition: The ability to cross-check measurements proposed against well-tested techniques.

Rationale: Validation is essential for evaluating how reasonable the assumptions, methods, and measurement approach are for determining the expected change in carbon pools.

Application: If measurements are done using well-tested, established techniques and protocols, validation may still be required if multiple techniques are deployed (e.g. for measurement across spatial scales). If new or innovative measurements are proposed, then the results of these measurements require validation against established methods. The assumptions and methods used should be appropriate for both the carbon pool and the context. Validation here differs from the same term used for GHG reporting, which considers validation as the independent assessment of data (e.g. by a third party).

6.1.3 Additional

Definition: The carbon sequestered beyond the *status quo* is additional to what would have occurred under business as usual and is attributable to the new mitigation activity.

Rationale: Demonstrating the link between a proposed activity or intervention and change in one or more carbon pools is essential for attributing changes to a new mitigation activity, and underpins estimates of carbon removals from these activities. To prove additionality, the emissions impacts of any new activities or interventions must be compared against baseline carbon stocks. Showing additionality is particularly important when, as may often be the case, the baseline is changing through time. Carbon sequestration trajectories under different management scenarios are then quantified, forecast or predicted. Proposed activities or interventions must quantify baseline carbon stocks, and then quantify, forecast or predict carbon sequestration trajectories under different management activities. At a minimum, this will require a counterfactual approach that considers the outcomes of *status quo* management or baselines versus the proposed activity.

Application: Additionality can be demonstrated against baseline conditions, but this can be accomplished in several ways, such as using land-use change models projecting forest sequestration rates without intervention, or other counterfactual process models or analyses. In some cases direct measurement is difficult and forecasts will require alternative approaches, such as using process-based models calibrated with field data. For example, in a grassland restoration project, 18 years of monitoring was required to demonstrate that the restoration activities increased soil carbon above the initial level of soil carbon at the site (Yang et al. 2019). Regardless of the approach deployed, all proponents must distinguish between the short-term transient GHG fluxes and carbon dynamics from longer-term carbon sequestration that meets the principle of *permanence* (see below). The additionality definition proposed is based on biophysical measurement of carbon, not as is used in a policy context for programmes that consider, for example, financial additionality as a proxy to demonstrate a new activity is beyond BAU.

Assigning causality to additionality will reflect both knowledge of the ecosystems and the ability to attribute changes in carbon sequestration to new mitigation activities. Often causality is assumed, but not demonstrated through measurement, nor is it verified against status quo or alternative management (see also elements of design in Allen, Forsyth et al. 2023). In most cases, management effects operate through one or more indirect pathways rather than affecting carbon pools directly. A rare example of a direct biophysical pathway would be the processing of biomass into biochar for the specific purpose of creating a long-term carbon sink. Most other examples either increase carbon sequestration or slow emissions though causal networks (see Peltzer et al. 2010).

Evidence for causality may be gained from modelling approaches, counterfactual analyses, previous measurements, or spatial comparisons. Disentangling the effects of a new activity from ongoing ecosystem changes or disturbance will also require documenting how causality is determined, and transparency about any assumptions and analyses for interpreting causation. This is an area of active research (e.g. distinguishing signal from noise in complex ecosystems; Suding et al. 2024).

Additionality is used in multiple contexts, across which its meaning or interpretation differs. More specifically, additionality for voluntary carbon markets (VCMs) is a distinct shift from business as usual made possible by the carbon market, whereas for the NDC, additionality indicates a change in carbon from baseline. For science principles we take an ecosystems view of additionality that is consistent with the biophysical interpretation used by NDC, rather than a market or policy interpretation as used by VCMs.

6.1.4 Permanent

Definition: A long-term increase in one or more carbon pools that leads to an increase in total carbon sequestration.

Rationale: One of the most critical aspects of high-quality carbon sequestration is permanence: the duration for which sequestered carbon remains stored and removed from the atmospheric carbon cycle. The durability or long-term fate of carbon is embodied in the principle of permanence. This principle includes consideration of two components: the long-term durability of carbon pools affected, and the risks associated with the pool.

Application: Carbon sequestration is only effective if increased carbon persists in one or more pools and leads to an increase in total stored carbon. From a carbon cycling perspective (cf. market definitions of permanence), permanence is generally best achieved by carbon being moved into recalcitrant or slow-turnover pools, but can also occur via more transient pools, provided continual carbon inputs maintain storage above the baseline. Projects must demonstrate predictions and assumptions for the duration of carbon gains even if permanence is not required *per se* for the NDC.

In practice no carbon pools endure permanently, but they should have predictable turnover or losses that guide quantification of duration or risk of loss (Desai et al. 2022). This is relevant both in terrestrial and aquatic systems under climate change because future risk from warming, disturbance or biogeochemical changes is likely (e.g. Seidl et al. 2017). For example, in blue carbon ecosystems, models integrating salinity, sedimentation, and mangrove growth data can predict durability thresholds under sea-level rise scenarios (Singh et al. 2022).

Duration of carbon stocks is usually considered as permanent if they persist for over 50 years, but this varies from decades in the tropics to centuries in the boreal climatic zone (e.g., Smith 2005).

Across ecosystems most studies suggest that relatively small quantities of new carbon inputs can be stabilised for over 50 years because of biogeochemical stoichiometry in ecosystems (broadly, climate, the water available and regolith constrain primary productivity through multiple biological processes). For example, in applications of biochar, sequestration efficiency ranges from 25 to 50% of feedstock carbon over 100 years.

There is no currently accepted standard for permanence (Keith et al. 2021). Ellis et al. (2024) consider acceptable 'reversal risk mitigation' for credible NCS carbon projects as a 68% probability of *partial* carbon stock reversal over a 50-year period, but data to understand changes in carbon stock reversals at the decadal scale are unresolved. Even though there is little consensus, we would expect proponents to demonstrate there is a high (e.g. 90%) probability that most (e.g. 80%) of the carbon sequestered from a new mitigation activity will persist after 50 years. Additional research is needed to quantify permanence, because this is a fundamental property of ecosystems and is linked to other principles such as *materiality* (below).

6.2 Science sufficiency principles

If a proposed activity meets the principles of science readiness, then additional considerations relating to the practical implementation of the activity are required. This second stage of 'science sufficiency' includes principles for ensuring a promising activity can be translated into real-world outcomes.

6.2.1 Material

Definition: There is a quantifiable effect size of a new mitigation activity on carbon sequestration at a scale meaningful for national carbon accounting.

Rationale: This principle is about the scaling up (i.e. magnitude of carbon response) and out (i.e. increased spatial scale) of effects on carbon sequestration that is of sufficient magnitude to warrant inclusion in the NDC.

Application: A material change to total carbon associated with the activity requires a *measurable*, *verified*, *permanent* change in carbon that can be attributed to a proposed activity (i.e. meets the principles for science readiness above). A *material* contribution requires effects that occur at broad spatial scales, either by being nationally representative or potentially applicable at a spatial scale that contributes to national carbon estimates. Materiality is a combination of effect size (i.e. the magnitude of change in carbon estimated) and the distribution of effects (i.e. the area affected and the duration of carbon gains). In addition, demonstrating material gains in carbon will guide which carbon pools and measurements are required, and their sources of variability and uncertainty.

6.2.2 Scalable

Definition: We consider *scalability* as the robustness of the measurements proposed (Allen, Forsyth et al. 2023), and how these measurements are capable of quantifying or monitoring the responses of carbon pools to the new mitigation activity across scales.

Rationale: Different measurements or methods are typically needed across spatial scales to demonstrate causality and the magnitude of carbon pool changes attributable to a new activity.

Application: Robust measurement, monitoring, reporting, and verification systems have been developed for GHG accounting and reporting purposes, and these can be usefully applied at the project scale (Gillenwater 2022; UNFCCC A6.4-STAN-AC-003)[7]. Scalability also includes the robustness of sampling and monitoring associated with measurement; this is crucial for quantifying the scale and magnitude of carbon responses to an intervention. Put another way, *scalability* is how measurement is deployed to quantify predicted changes in carbon.

An additional consideration is scaling measurements to quantify the spatial extent of the effects of an intervention, which could involve multiple types of measurements and methods used in combination. For example, spatially tiered monitoring deployed for some verification schemes (e.g. Stanley et al. 2023) includes a combination of measurements across scales such as:

- landscape scale (e.g. remote sensing of above-ground biomass
- site scale: field plots (e.g. 1 ha/100 km^2) measuring biomass, organic matter and soils
- point scale (e.g. eddy covariance towers or chamber measurements for flux validation).

Some international studies demonstrate that high spatial accuracy of carbon measurements requires additional data on land use and management, high-quality vegetation information, and soils to quantify the effects of proposed activities (interventions), or to build accurate predictive forecasts/models of effects (Smith et al. 2020).

6.2.3 Leakage

Definition: The unintended increase in carbon losses outside the project boundary that is a consequence of the new mitigation activity. This can be either by direct escape of stored carbon from its containment or by causing increased emissions elsewhere.

Rationale: Leakage undermines the net carbon sequestration that occurs from a new mitigation activity. This principle is about identifying and understanding critical spatial effects and linkages that affect carbon. Leakage is well established in the literature and carbon accounting because of

[7] UNFCCC. A6.4-STAN-AC-003. Standard: Article 6.4 validation and verification standard for projects. Version 02.0. https://unfccc.int/sites/default/files/resource/A6.4-STAN-AC-003.pdf

concerns that well-intentioned carbon sequestration or GHG emissions reduction activities could have perverse outcomes, unintended negative consequences, or overestimate material effects on carbon. Recognising leakage as a principle flags a need for its effective recognition, monitoring, and clear accountability within a robust framework. This principle is about identifying and understanding critical spatial effects and linkages that affect carbon.

Application: Because leakage means the overall level of carbon sequestration from a new mitigation activity will be effectively lower it is crucial to understand and avoid, but also measure, its consequences. What needs to be avoided is complex, because leakage involves a range of direct or indirect consequences of the activity as biophysical effects. A direct consequence might be that the mitigation activity increases the use of resources (e.g. fuel) sourced outside the project area. Indirect consequences such as the removal of old-growth forest and adjacent replacement with a new forest (which is claimed as a new activity) should be avoided.

Leakage also refers to situations where efforts cause degradation outside of the project area (such as fertilisation to enhance the rate of sequestration in a forest, but where the fertiliser nutrifies an adjacent wetland, which in turn becomes a weaker carbon sink). Proponents would have to demonstrate that their *measurement* and *transparent* design account for all unintended carbon leakages.

6.2.4 Transparent

Definition: There are documented and accessible designs and data collection on carbon sequestration measurements, as well as data quality standards, analyses, and interpretation.

Rationale: Transparency of data, analysis, and interpretation is crucial for understanding the quality and integrity of the evidence base used to assess a change in carbon pools from a proposed activity.

Application: Transparency enables the public or a third party to assess the quality and robustness of information, and underpins other principles such as *measurement*, *additionality*, *leakage*, and *permanence*. Transparency and access to information are becoming increasingly expected for large-scale analyses of environmental condition (Powers & Hampton 2019) and GHG reporting, and should be a requirement for any contribution that is counted towards New Zealand's NDC. At a minimum, the underlying data, assumptions, and calculations should be available for independent quality assurance, reproducibility of results or predictions, and peer review. The principle of transparency is also essential for GHG inventory accounting to report on progress against internationally agreed targets, such as those set out in the Paris Agreement (see also Climate Change Commission 2024; MfE 2025a).

6.2.5 Sustainable

Definition: The impacts of a new activity on biodiversity, ecosystem processes or services.

Rationale: Sustainability is required to ensure that proposed activity considers both positive and negative effects on biodiversity or ecosystem services, and that the benefits of the activity are maintained.

Application: This principle highlights the importance of considering the wider ecosystem effects of a new activity, whereas *leakage* considers only the effects on carbon pools. Sustainability requires an assessment of the co-benefits (both negative and positive) of an activity to other biophysical outcomes, and may reveal trade-offs among carbon and other ecosystem responses. The principle of sustainabilty has close links to the principles of *permanence*, *leakage*, and *materiality*, in that activities that are material, enduring, and have no leakage should also exert other changes to an ecosystem.

For proponents of new activities, sustainability requires an assessment of linkages or trade-offs between increased carbon or other effects of the activity (e.g. alteration of ecological processes or spatial configuration of habitats) and other ecosystem properties or processes. Additional sustainability considerations to do with markets, policy or co-benefits are required for consideration in steps following after science assessment (e.g., Fig. 1).

This principle is very broad, covering potentially many concepts of ecosystem process, services, and biodiversity thus requiring cross-disciplinary expertise to evaluate. Sustainability should also be considered as a criterion to distinguish quality differences among projects.

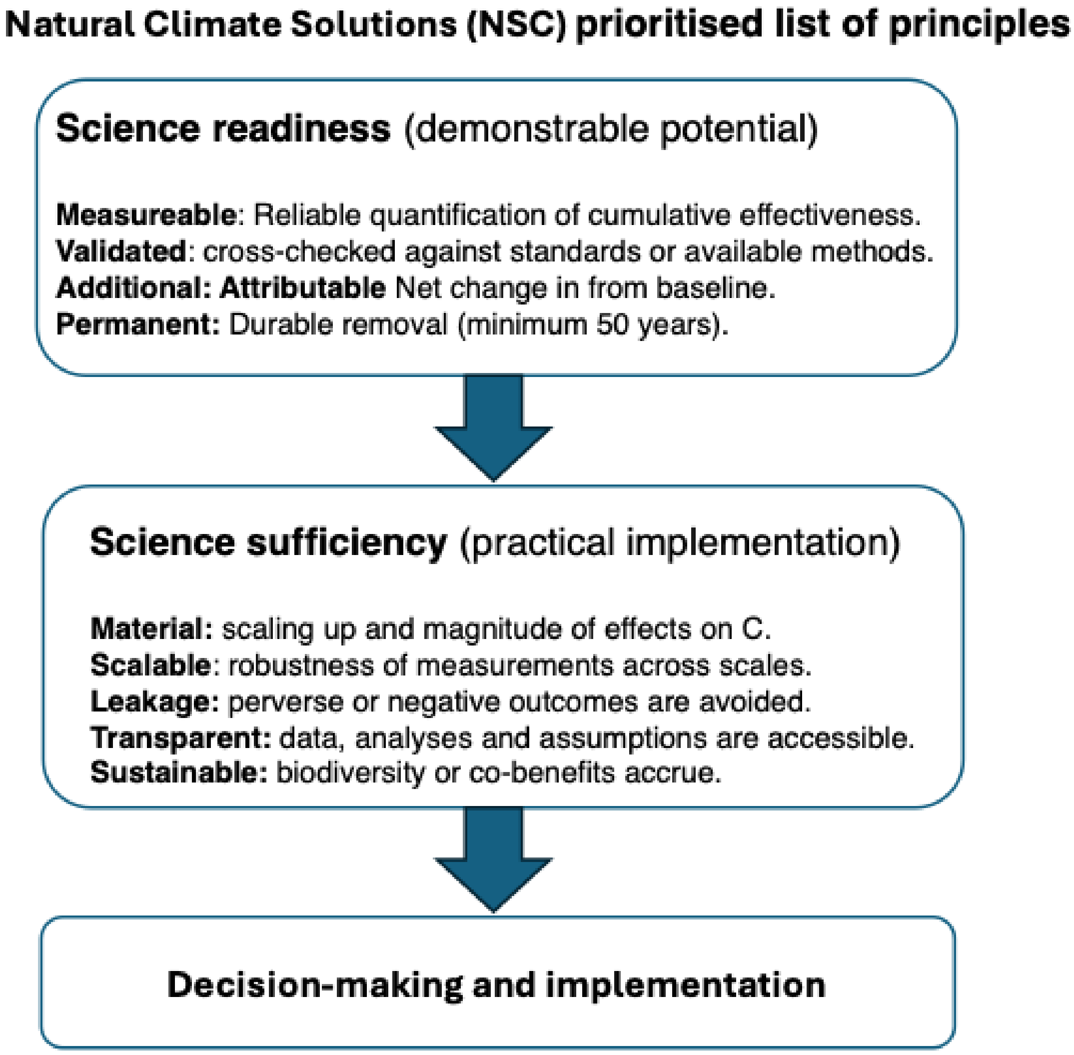

Figure 3. Illustrative summary of science readiness and sufficiency demonstrating key principles for each stage.

6.3 Broad implementation guidelines

Any new NCS mitigation activities to be included in New Zealand's NDC must also be reported in New Zealand's GHG Inventory, which must follow IPCC guidelines (not covered in Ellis et al. 2024). The IPCC provides guidelines for national GHG inventories and standardised methods for reporting on land-based carbon fluxes in vegetation and soil, ranging from Tier 1 defaults through to country-specific methods that are either simple (Tier 2) or advanced (Tier 3) modelling techniques. This standardised methodological guidance from the IPCC provides a practical framework for identifying the research required to develop methods for accounting for emissions and removals is a way that is suitable for inclusion in New Zealand's NDC.

In the case of VCMs, measurements must be validated and verified to demonstrate additionality, and in some cases this will require testing new methods alongside established techniques. In the case of GHG inventories and NDCs, measurements are subject to technical expert review to ensure reporting guidelines are adhered to.

In all cases, measurements must be *validated* and demonstrate *additionality* (all principles outlined above in section 6.2). In some cases this will require testing new methods alongside established techniques. Although there could be different requirements for a new activity to contribute to a VCM or the NDC, in all cases validation of the techniques for measurement is required prior to validation and verification of sequestration. Measurement cost is an important consideration. If the cost to ensure that an intervention's impact is measurable is greater than the financial rewards from net GHG removals achieved, than the intervention may not be financially feasible. This will be an important element for a project proponent to consider and otherwise be factored into decision making following the science evaluation phase.

6.4 Confidence and weight of evidence

For any principle (normative criterion), strong evidence is needed to have confidence in evaluating the quality of the proposed activity (see section 6.3). Confidence weightings are widely used to rank the reliability and strength of the data, evidence, and approach, and are used to decide whether more information is required for an activity or intervention to proceed. For example, the IPCC has used a combination of scientific agreement and quality of data or evidence to qualitatively rate the confidence in an outcome from low to high (Figure 4).

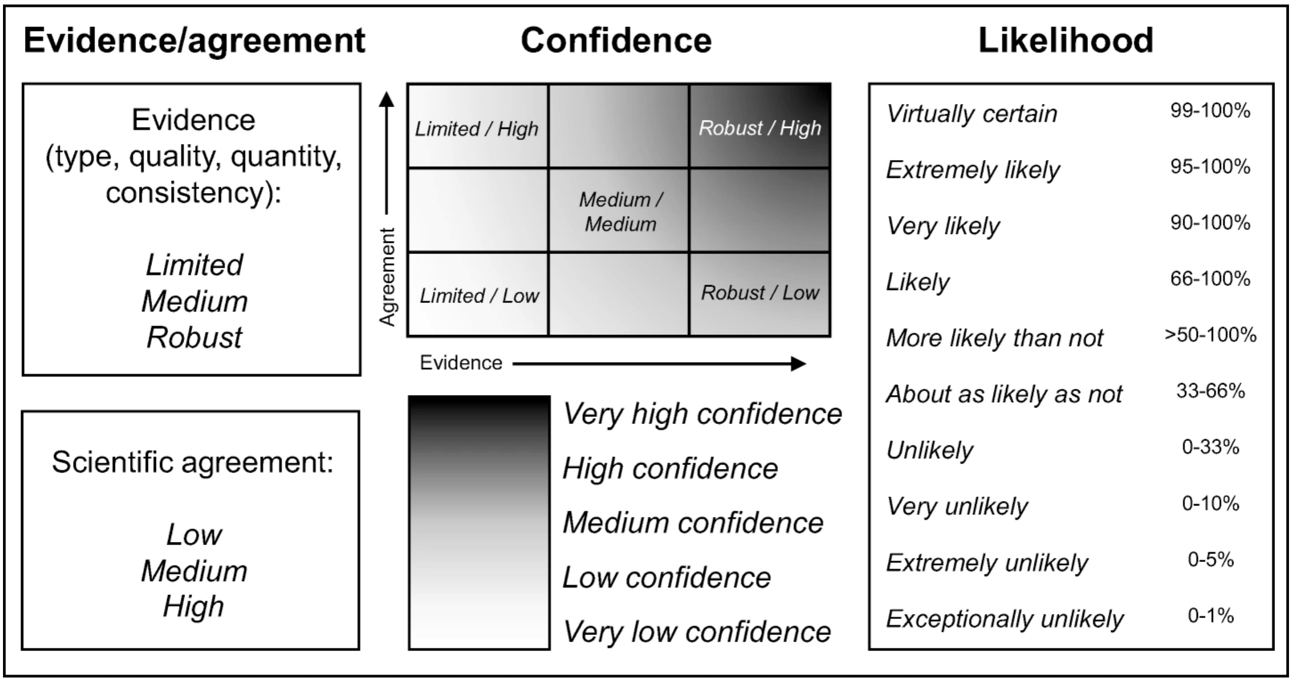

Figure 4. The IPCC rating of confidence, which uses a combination of evidence quality and agreement to describe uncertainty as confidence; this is increasingly used in preference to likelihood statements. (Source: figure reproduced from Janzwood 2020)

The principles in the science framework developed here are normative *criteria* for guiding decisions about the quality and confidence of the evidence for the carbon sequestration from a proposed activity. The confidence in the data or analysis and the weight of evidence provided for each piece of evidence for each principle should be used to evaluate their relative strength or merit. There is no agreed method for rating confidence, but several promising approaches are available that could be used, such as the IPCC rating of confidence (Janzwood 2020), GRADE[8] or the IPBES qualitative ranking of confidence (IPBES 2018). For example, the IPCC uses ratings of confidence that can be interpreted as the likelihood of effects for specific measures of GHG emissions or climate change; these likelihoods are driven primarily by biophysical science measurement (Janzwood 2020; Kause et al. 2022; McElwee 2025). The GRADE[8] tool is used to assess the certainty of evidence and strength of recommendations about the effectiveness of interventions in health that could be applied to NCS/NbS projects (e.g. Guyatt et al. 2008; Prasad 2024). However, the IPBES qualitative ranking method holds the greatest promise for application to NCS because of the types of projects and the range of data or knowledge the natural carbon sequestration framework is likely to be applied to.

Qualitative confidence levels could be applied to any criteria or component data/knowledge following the IPBES (2018) approach (Table 1). For example, GRADE assigns confidence qualifiers to data or key statements based on current levels of evidence and agreement using four qualifiers from low to highest confidence:

- **inconclusive**: existing as or based on a suggestion or speculation; no or limited evidence

[8] Grading of Recommendations Assessment, Development, and Evaluation

- **unresolved**: multiple, but weak, independent studies; data or theory/models exist but conclusions do not agree
- **established** but incomplete: general agreement from a limited number of studies, but with no comprehensive synthesis, or the studies that do exist imprecisely address the question
- **well established**: comprehensive meta-analysis or other syntheses; multiple, robust, independent studies that agree.

Although there is no hard rule on how strength of evidence statements are used in decision-making, a precautionary approach is required when interpreting statements of low quantity and quality of evidence. Low evidence (i.e. 'inconclusive' or 'established but incomplete') does not necessarily imply that a relationship or process is unimportant, but could reflect previous technical or measurement limitations, paucity of studies, or novelty. Regardless of the approach adopted for defining the quality of evidence, using principles as criteria in decision-making will require clear instructions on how criteria are evaluated for proponents of the activities, or expert guidance from government or highly qualified personnel.

Table 1. Summary of IPBES (2018) qualifiers for level of confidence as they could be applied to decisions for inclusion of new activities or interventions in NCS

Level of confidence	Description	Decision
Inconclusive	No evidence or data are available to support the claim of carbon gain. Hypothesis unlikely.	New data, models or studies are required before proceeding.
Unresolved	Some data are available but they could be highly variable, or different results reported. Hypothesis plausible.	Additional research, data or evidence are required.
Established but incomplete	Multiple studies, data sets or independent lines of evidence demonstrate the potential of the activity, but some additional information or data would fill gaps or provide system-specific knowledge.	Proceed to consider policy or other criteria for inclusion in the NDC or other system. Some synthesis or additional evidence may be required.
Well established	The outcome is well supported by multiple studies or lines of evidence, and by independent investigators. A demonstrable evidence base for activities and outcomes for carbon.	Proceed with high confidence to implementation stage.

7 Illustrative case studies of new activities

Understanding how the science framework principles might be used as criteria is an important next step, but is beyond the scope of the current report. However, we consider several contrasting case studies or exemplars below, and discuss how the science framework might be applied to decision-making about the quality of evidence for a proposed activity and its potential inclusion in one or more schemes. These examples are illustrative only to demonstrate how the principles and framework might be applied to different potential new activities.

In addition, we emphasise that any assessment requires the most current knowledge or data available: in some cases this will include recent peer-reviewed publications as the strongest independent source of knowledge, but could include recent developments or innovations in science or monitoring techniques. We do not provide a rigorous assessment of the science or information available for each case study, but what we have provided could be used as a starting point for proponents to guide what data, information or evidence would be required to meet the science criteria in the framework.

7.1 Browsing animal management

A number of mammal species have been introduced to New Zealand, including ungulates such as deer, goats, tahr and chamois, along with smaller-bodied animals such as brush-tailed possums and rabbits. This suite of browsers now occurs nationally and has no historical analogue in the native fauna. The measured or perceived damage caused by these species has prompted broad management efforts that seek to limit diseases, protect or restore biodiversity, and, most recently, potentially enhance carbon sequestration (Carswell et al. 2015; Peltzer & Nugent 2023; Hawcroft et al. 2024). Could the management of browsers result in appreciable gains in carbon sequestration (Peltzer et al. 2010; Tanentzap & Coomes 2012; Holdaway et al. 2012)?

Science readiness (demonstrable potential)

- *Measurable:* Reliable quantification of cumulative effectiveness has been established using national, plot-based measures of vegetation, including browser exclosures (e.g. Coomes et al. 2002; Tanentzap et al. 2009; Allen, Bellingham et al. 2023). That is, there are established measurement procedures developed that could generate appropriate carbon sequestration data to demonstrate a change, but not specific measurements for detecting browsing species-specific effects at a national scale.
- *Validated:* Validation of vegetation and soil measurement protocols, data collection methods, and analytical approaches is *well established* for the quantification of carbon stocks (e.g. Holdaway et al. 2014).
- *Additional:* Carbon gain from browser management is *uncertain* because carbon responses are rarely attributable to the control or management of one or more browsing species, the impacts may not be reversible (e.g. Coomes et al. 2003), or effects are implied rather than measured (e.g. by measuring plant species that are thought to be palatable to herbivores; Bellingham & Lee 2006). Moreover, a claim of additionality would require there to be new browser management as a mitigation activity rather than business as usual.
- *Permanent:* Durable removal (a minimum of 50 years) is unlikely (*inconclusive*) without long-term elimination or eradication.

Assessment outcome: Measured responses of carbon to browser management reported by several studies are zero to small effects, suggesting the overall science readiness is *unresolved*. Browser management will likely continue to occur for biodiversity or game animal management goals. Better information on *additionality* and *permanence* are required and are areas of active research and investment currently. Given this state of knowledge, science sufficiency could be considered.

Science sufficiency (practical implementation)

- *Material:* Although browser management could occur at regional to national scales, the magnitude of effects on carbon is small to negligible. Net change in GHG or carbon storage from baseline is *uncertain*: several studies point to browsers as having small and variable effects compared to other drivers and dynamics. The material effects of this management are *inconclusive*.
- *Scalable:* The national distribution of introduced browsers and their potential for management is *well established*, although their density and effects are highly variable across sites.
- *Leakage*: Perverse or negative outcomes from browser management are possible (e.g. by additional carbon emissions associated with management activities such as travel or helicopter operations, or prioritising browser management over other activities that could generate larger carbon gains). This is *established* by several studies on the management responses of vegetation and biodiversity.
- *Transparent*: This is *unresolved*, because data for animal management outcomes, including the population responses of pest species, are not well documented or available; data, analyses and assumptions could become more accessible in the short term, with effort.
- *Sustainable*: Co-benefits for biodiversity and disease management are *well established*.

Assessment outcome: Browser management itself is well implemented at scale, but the *material* impacts of this management on carbon are, at best, *unresolved*. Increased data collection or research on *additionality* is unlikely to increase *materiality* of browser management impacts on ecosystem carbon. The main issue is that there are well-established methods for measuring carbon, but relatively less effort has gone into quantifying management outcomes.

7.2 Increasing soil carbon using diverse pastures

Background: Globally there is an interest in increasing soil carbon through improved land management (e.g. Paustian et al. 2016; McClelland et al. 2025), requiring good scientific knowledge of plant–soil–animal interactions (Keiluweit et al. 2015; Jackson et al. 2017). In New Zealand, one promising change to grassland management is using diverse pastures containing mixtures of plant species. Diverse pastures are expected to be more resilient, require fewer inputs (e.g. fertiliser), and potentially improve animal health (Romera et al. 2017). Could diverse pastures also be considered as a new activity for increasing soil carbon longer term?

Science readiness (demonstrable potential) criteria with qualitative ranking of evidence

- *Measurability* is *unresolved*: Reliable quantification is possible, but few measurements have actually been made.

- *Validation* is *well established*: No new techniques are required: there are available standards or methods.
- *Additionality* and *permanence* are *unresolved*: International studies in semi-natural cut grasslands have reported higher soil carbon stocks in more species diverse treatments, likely related to greater root biomass and depth. In grazed pastures in New Zealand, greater root biomass has been observed under more diverse swards but not higher soil carbon stocks Whitehead et al. 2024). Causality is unresolved because carbon gain has not been measured, but could be attributed to the activity or intervention with more research or data collection.

Assessment outcome: The evidence for soil carbon additionality and permanence is lacking. New data and research are required to demonstrate measurability and causality. As a result, do not proceed to science sufficiency assessment. However, given the potential co-benefits to nutrients, animal welfare, and the scalability potential of this activity, additional efforts for data collection should be supported.

7.3 Coastal restoration

Coastal marine habitats such as mangroves, seagrass beds or saltmarshes might sequester substantial carbon. Such marine sinks are called 'blue carbon'. Some propose that restoration of marine habitats could reverse historical declines in blue carbon caused by pollution, declines in foundation species, habitat degradation or coastal development (Pessarrodona et al. 2023; Bulmer et al. 2024; Macreadie et al. 2025). As a consequence, coastal blue carbon initiatives are an attractive proposition in New Zealand given our relatively large coastal areas and potential for restoration or changed management (Stewart-Sinclair et al. 2024). Could coastal restoration increase carbon sequestration that could be claimed as carbon credits?

Science readiness (demonstrable potential) criteria with qualitative ranking of evidence

- *Measurability* is *unresolved*: Reliable quantification is possible but is *unresolved* because few measurements have actually been made.
- *Validation* is *unresolved*: Marine coastal habitats are highly dynamic and variable, relying heavily on modelled estimates: some new techniques or measurements of coastal carbon dynamics are required.
- *Additionality* and *permanence* are *unresolved*: Coastal restoration may or may not have additional effects on total blue carbon over the long term beyond *status quo* management; additional measurement, modelling or understanding of the *materiality* of restoration interventions are needed. Carbon gain has rarely been measured, only estimated. The mobility of sediments, organic carbon, and dissolved carbon in marine systems at the terrestrial interface makes attribution of management to carbon changes complex and difficult to demonstrate. Complex changes in marine environments, such as sea-level rise and disturbances, are an increasing risk for permanence.

Assessment outcome: The evidence for marine restoration additionality and permanence for blue carbon is preliminary. New data and research are required to demonstrate measurability and causality. As a result, do not proceed to science sufficiency assessment. However, given the multiple co-benefits to biodiversity, habitat integrity, and coastal or inshore environments, and the high potential for scaling up or out activities, additional research and data collection should be supported.

7.4 Peatland restoration

Background: Drained peatlands used for agriculture (primarily dairy pasture) represent about 1% of New Zealand, but GHG emissions from the soil (not including grazing animals) contribute about 7–8% of national emissions (Pronger et al. 2025; Whitehead et al. 2024). In contrast, measurements in remnant natural peatlands in the Waikato have revealed that these systems are net GHG sinks (Campbell et al. 2014; Goodrich et al. 2017; Ratcliffe et al. 2019). Restoration of drained agricultural peatlands to indigenous ecosystems therefore has the potential to turn a large source of emissions into a net sink.

International research by Evans et al. (2021) has shown that GHG emissions from peatlands are reduced when water tables are higher, and they argue that raising the water table of peatlands under continued agricultural use could reduce global emissions (see also Girkin et al. 2023). Whitehead et al. (2024) used relationships developed by Evans et al. (2021) and estimated that if water-table depth were reduced on 33% of New Zealand's drained peatlands (i.e., water level was raised or restored), national GHG emissions could be reduced by about 2%. Of nine interventions assessed (in relation to soil carbon), reducing water-table depth was the only one assessed as having a confidence level of 'likely' to reduce emissions (Whitehead et al. 2024).

Science readiness (demonstrable potential) criteria with qualitative ranking of evidence

- *Measurability* is *unresolved*: Reliable quantification is possible, but few measurements have actually been made and current methods are expensive.
- *Validation* is *well established*: No new techniques are required: there are available standards or methods.
- *Additionality* and *permanence* are *unresolved*: The short-term effects of peatland restoration are emissions reductions compared to *status quo* management. Over the longer term (50 years), restoration could also have additional effects on soil carbon. Causality is unresolved because carbon gain has not been measured, but could be attributed to the activity or intervention with more research or data collection.

Assessment outcome: Additional data or information is required for measurability and causality.

8 General discussion

8.1 Links to carbon markets

Voluntary carbon markets (VCMs) are sufficiently mature to demonstrate the fundamental criteria required to provide *market* confidence (cf. scientific criteria) in the veracity of the carbon units created. The Verified Carbon Standard (VCS) programme is the world's most widely used GHG crediting programme, and is derived from transparent scientific data and evidence to support emissions reduction, livelihoods, and improved environmental conditions. The Climate Group, the International Emissions Trading Association, the World Economic Forum, and the World Business

Council for Sustainable Development developed the VCS to provide a robust, global standard and programme for the approval of credible voluntary offsets (e.g. http://www.v-c-s.org). Consistencies in principles between approaches could offer the opportunity for proponents and activities to meet obligations for both voluntary markets and national requirements.

One major point of difference between NDC and VCMs is in terms of how additionality is considered. For VCMs, additionality is related to unlocking a new activity that is currently rare in the marketplace through financial or policy mechanisms beyond business as usual. In contrast, for NDC, additionality is the new carbon contribution beyond baseline or emission estimates that must adhere to reporting requirements under the Paris Agreement. The accounting rules that are applied to the LULUCF[9] sector in the NDC are based on a 1990 baseline, and are used to report net emissions from activities that have occurred. In practice, the NDC approach seeks to incentivise additional action but does not have to demonstrate additionality in the way this is treated for VCMs.

Many of the VCM criteria are consistent with Climate Change Commission (2024) advice on national emissions reporting; for example, the Commission's recommendations to adopt the principles of additionality and permanence (durability), and to include these as criteria for any recognised carbon removal activities, alongside removal capacity, measurability, cost, and acceptability. Some of these criteria are included in the science framework developed here, but other criteria about markets and policy consideration are outside of scope here. A summary of requirements needed for science assessment, and how this could help to assist proponents of new activities develop a case for inclusion in either the NDC or VCMs, is a next step (Figure 1; see also 'Additional principles for programme evaluation' and 'Recommendations' below).

8.2 Transparency, robustness, and access to information

Implementing the science framework as criteria requires expert knowledge or clear guidance on the use of evidence. For example, the type, quality, quantity, and consistency of evidence underpin any qualitative or semi-quantitative ranking of evidence strength. Increasingly, both in science publication and in investment tracing for markets, transparent processes and documentation of data, analyses, and interpretation are required.

8.3 Additional principles for programme evaluation

Several additional principles have a component of science content but are primarily related to policy or implementation, and should be considered as part of programme requirements. Briefly, these include the following.

Viability: Both social licence and economic feasibility underpin whether a proposed activity is feasible, in addition to technical and logistical considerations captured by the science framework.

[9] Land Use, Land Use Change and Forestry.

Equitability: NCS should be implemented in a way that is fair and equitable, considering the needs and rights of local communities and indigenous people. This ensures the benefits of NCS are shared broadly and do not disproportionately affect vulnerable populations.

Culturally appropriate: Cultural acceptance and support for the proposed activity: in New Zealand the appropriateness of management actions should be guided by the Treaty of Waitangi.

Co-benefits: Management of carbon *per se* is rare for nature-based climate solutions (NbCS); rather, co-benefits for biodiversity, environmental condition, or human welfare or livelihood are also sought. Benefits to biodiversity are anticipated to include increases in habitat quality, populations of rare or threatened species, or contribution to broader ideals such as ecosystem integrity (Loher et al. 2024; see also Cohen-Shacham et al. 2019; Bellingham et al. 2020).

Risk: robustness to future disturbances or processes is embedded within the principle of permanence, but additional consideration of risks driven by markets, viability, and social or cultural support is warranted.

Nature-based: NCS ultimately rely on ecosystems to capture and store carbon (Griscom et al. 2017). Although it is not essential that proposed activities be nature-based, NbS are preferred because they generally meet principles of *sustainability* and generate *co-benefits* (Osaka et al. 2021; Novick et al. 2024; Ellis et al. 2024). In practice, these principles should be addressed by programme-level evaluation shaped by policy needs or market access.

8.4 Unresolved issues

Although we have identified leading principles from a rapid assessment of the literature, the principles themselves are ideals. Similarly, Ellis et al. (2024) recognised that real-world complexities, uncertainties, and actions require that the application of these principles as criteria will require an adaptive approach. These principles and framework will ideally enable decision-makers such as proponents, markets and government, to act on robust, transparent evidence. As this framework is tested and implemented, several unresolved issues are likely to require consideration and resolution in future interactions when applying the Scientific Framework, including the following.

- Both the principles and their deployment as criteria for decision-making will require ongoing evaluation to ensure NCS activities are additional and effective for GHG removals.
- Co-benefits of NCS to biodiversity, environmental conditions (water, air, soil), human well-being, and climate resilience are often desired or anticipated, but rarely quantified. Better knowledge of and data for co-benefits or trade-offs are required to understand the magnitude of co-benefits, and when or where these occur (Mariani et al. 2024).
- Multiple future threats and uncertainties associated with carbon stocks are likely, requiring better forecasts or estimates of key risks such as disturbances, droughts or invasions (this is especially relevant for durability or the permanence of removals). One fundamental issue is that carbon is 'slow in, rapid out', so that sequestration is far more difficult to demonstrate than rapid losses from disturbance (Körner 2003; Anderegg et al. 2020).
- While we focus here on nature-based solutions, and these should be prioritised where possible because of multiple spillover benefits that increase their value or credibility, this framework can be applied to other removal activities.

- Monitoring linked to forecasting is essential for validating methods and compatability with national reporting requirements, and to accurately estimate removals.

Over time it may be necessary to add or adjust principles. The overarching outcome from this work is to support the identification and adoption of robust and durable NCS that could meaningfully contribute to climate change mitigation.

More generally, there is also a globally urgent need to adopt participatory approaches, and to increase inclusion of local and indigenous peoples (e.g. Carmona et al. 2023). This can have quantitative benefits; for example, participatory monitoring networks increase data reliability by 37% compared to top-down approaches in Sweden (Eicken et al. 2021). In New Zealand the enduring goal of effecting the principles of the Treaty of Waitangi alongside the growing importance and scale of post-Treaty land use requires greater attention to cultural and environmental co-benefits. Many activities will happen regardless of carbon, so how do we better consider these broader goals/objectives alongside carbon management?

9 Recommendations

- Guidance on transparency and strength of evidence is required, both for proponents and for decision makers. We suggest adopting the IPBES (2018) framework for this initially, because it is simple and well established, and will work across the different principles and diverse data or evidence used by proponents.
- Just how this *natural carbon sequestration science framework* is embedded within decisions about inclusion in the NDC or other carbon accounting systems needs to be considered (Figure 1). A user-friendly summary and guidance for decision-makers would help to identify the relative scientific strengths or merits of proposals. This could include FAQs, or using the science framework as a basis for initial questions about inclusion in the NDC or other schemes by proponents.
- Measurability and additionality principles are essential: if a proponent cannot demonstrate carbon gains or removals, or attribute them to management or interventions, then recognition cannot be justified. Additional research or evidence could be identified, guided by the science framework, to improve the strength of confidence that the proposed activity meets these principles.
- In many cases involving innovative or novel approaches, forecasting or counterfactual models should be considered as evidence. This requires expertise to interpret the robustness and strength of predictions, and transparency about the assumptions and analysis.
- Many natural climate solutions activities are motivated by co-benefits such as biodiversity, environmental and socioeconomic indicators alongside carbon sequestration. Consider and quantify co-benefits as part of decision making about implementation (Fig. 3).
- Ultimately the science framework presented here sits within a wider science, policy, and practice system being actively developed in New Zealand, but how these elements are linked to evaluate and support NCS requires additional consideration and development.

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Glossary

Term	Definition
additionality	a measurable change in carbon from baseline
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
MfE	Ministry for the Environment
NbS	nature-based solutions
NDC	nationally determined contribution
NCS	natural climate solutions
Scientific Framework	The science assessment framework developed in this report
Treaty of Waitangi	New Zealand's founding document that was meant to be a partnership between Māori and the British Crown
VCM	Voluntary Carbon Market
VCS	Verified Carbon Standard