Michael Mauri, Licensed Forester
& M.S. Forest Ecology and Management,
20 West Street, South Deerfield, MA, 01373
(413) 665-6829; mikemaur@crocker.com

January 24, 2024

Dear EEA and Climate Forestry Committee, Please accept these comments as part of your public input process.

The Climate Forestry Committee report commissioned by Gov. Maura Healey and issued on January 4, 2024, reflects a significant effort by EEA and the Committee members and embodies a significant amount of content. I would like to thank the EEA and the Committee.

No doubt a somewhat thankless task to write, the report is well-written overall, but requires careful attention and interpretation by those, such as myself, who are forest practitioners in Massachusetts.

The report is clearest when the committee members were in agreement, and much less clear when the panel of experts was divided, as it often was. Perhaps a main point is that we need to keep as much of our forest as possible on the one hand, and that we cannot and should not think of the forest solely in terms of carbon, which is only one of its many important aspects, on the other hand.

Another key starting point in the report is the strong agreement, backed by data, that "Massachusetts forests currently store vast amounts of carbon and continue to sequester additional carbon each year." It is perhaps worth mentioning here that the high levels of forest carbon found in our forests reflect to a certain extent the general forest practices pursued in our area over the past 100 or so years – including our laws and regulations, the choices that agencies, landowners and practitioners make, and the skills and dedication brought by practitioners into countless situations over the years. Though some critics refer disparagingly to the current practices in Massachusetts as "business as usual," and though there is always room for improvement, the fact is that, when compared to our fellow New England states, the Report shows us cutting a pretty good carbon figure.

Another point of agreement in the report was that, after rapid early growth, the rate of carbon sequestration slows down as forests mature[1], a claim strongly backed by research

[1] "There was some disagreement on the Committee relative to the age at which forests sequester the most carbon. While it was accepted that younger to middle aged forests sequester carbon at a higher rate than older forest, Committee members did not agree on the specific age range at which sequestration is maximized." Climate Forestry Committee Report pg. 31

across a wide range of forest types in the Continental U.S.[2] Our forests are maturing and, currently, the Report states, that the forests of Massachusetts as a whole have "plateaued" in their carbon growth, (see page 17-18). This is important to state, because, often, just the opposite claim is made.

Finally, there was agreement on the following: "Most forests in Massachusetts can continue to accumulate carbon for decades to come, though uncertainty about major disturbances and other ecological processes (e.g., age-related decline in tree growth, climate change impacts, regeneration) makes it challenging to precisely quantify future potential carbon storage levels and sequestration rates" (see page 18). The one thing that is certain is uncertainty.

Against this backdrop, one major upshot is that the land-owning agencies are asked to more explicitly consider the carbon implications of forest management above and beyond the business as usual way of doing things which, as stated above, has already led to an elevated accumulation of carbon. This request is the case whether the forest management of the agency focuses on wildlife habitat, protecting water quality, generating locally-grown timber, or other goals. The hope is that, with creativity and an intensified appreciation of mature-forest processes associated with greater carbon storage, the agencies can eke out more carbon storage from our public forests while at the same time avoiding reductions in other services.

It is curious that the Committee was divided on the benefit of locally harvesting wood for use as timber and other forest products. While reduced cutting in Massachusetts would certainly help with our *in-state* carbon bookkeeping (as we pursue statutory emissions reductions), sheer common sense would seem to dictate that, if we continue to use just as much wood as we do now, then our wood will merely be cut somewhere else – as some Committee members did mention. As a result, the global carbon needle would actually stay the same or, even worse, register an increase in atmospheric carbon, while at the same time we would become ever more disconnected from the land, asking for essential resources to be sent to us from far away.

Throughout the report, one sees a tendency of recommendations leaning toward passive management that lets forest continue to age, but also a recognition that each situation is unique. Common sense says that a passive approach will work best when the forest is in fact already functioning at its best. A forest that is not functioning well will degrade over time, and thus, the more degraded a forest is in terms of its ability to properly function, the more active support it will need if indeed we wish to avoid reductions in the services we rely on, including carbon services. Our forests are directly and indirectly affected by pests, pathogens, invasive plants, high deer populations and, of course, any ravages of climate change itself, and so it would seem that many areas of forest will not be able to function properly, and thus will actually need some measure of management support (if

[2] See Hoover, Coeli M., and James E. Smith. "Aboveground live tree carbon stock and change in forests of conterminous United States: influence of stand age." *Carbon Balance and Management* 18, no. 1 (2023): 7.

we truly care about the outcomes). Ultimately, the passive versus active debate is a sort of red herring; passive and active are questions of degree, not absolutes, and the concern for us should not be how passive or active we are, but rather how well the forest is functioning, and what, if anything, can and should be done at ground level to improve it, and how well we do it.

One regrettable surprise was the Committee's expressed hope that, as part of the Eastern U.S. forest, Massachusetts forests might *double* their carbon storage if passively allowed to grow (see page 32). This stands at odds with what the Committee had already said previously in the report (see above). Curious, however, I followed the research cited by the report to support this claim and learned that the term "Eastern U.S." actually refers to a vast area of forest from Minnesota and Michigan to Maine and Massachusetts.[3] With further research, I learned that many of the large states in this region have much less carbon in their forests (on a per-acre basis) than current-day Massachusetts. For example, Massachusetts forests in the 60 – 120 year old age range already have 50% more carbon than same-aged forests in Maine and Michigan and *twice as much* carbon per-acre as same-aged forests in Minnesota![4] It would seem that the big increases to come, if they do, would be in those large-acreage states that currently have much lower per-acre carbon levels. Furthermore, the claim of regionwide doubling in carbon is based – and the authors do state this – on an assumption that climate change will not cause an increase in disruptions of the forest over the coming decades. This is a remarkable assumption given how much effort we are devoting to preparing for the disruptions of climate change. I worry that the Climate Forestry Committee report's claim of doubling carbon, implied on page 32, could be taken out of context and mis-used as an argument against active forest management on the basis of carbon trade-offs. It would be helpful if the Committee could clarify this.

Another surprise for me was the report's claim that, through natural disturbances that knock down trees, such as windstorms, the forest can, or rather "may," protect itself from the impacts of high deer populations. I would love nothing more than for this to be true, but in the parts of central and Western Massachusetts where I work, I see no evidence that it is true. Currently, at their high level, deer consume a significant amount of the diverse young trees we'll need going forward. The three references cited in the Committee's report to back up this claim of *protection through disturbance* include a paper published in 1960 (by all means, roll back the clock and give us those lower deer populations from over 60 years ago!), a paper regarding old growth forests in Poland (where they still have wolves to drive and hunt deer!) and an undergraduate thesis. If we really want to see our forests thrive, which we do, we need to do a much better job protecting young trees from the excessive browsing of our in-state deer populations; we need to do a much better job bringing our deer populations into alignment with our

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[3] Birdsey et al. 2023. Middle-Aged Forests in the Eastern U.S. Have Significant Climate Mitigation Potential. *Forest Ecology and Management* 548: 121373.

[4] See supplemental table S4 in Hoover, et. al. (2023).

fundamental need to successfully establish a full diversity of young trees that will sequester carbon and provide a whole range of other services well into the future. Thank you.

Michael Mauri is a practicing forester based in South Deerfield.

To: EEA Climate Forest Committee, January 19, 2024
Fr: Bruce Spencer, Retired Chief Forester Division of Water Supply Protection
RE: Comments Concerning Carbon Sequestration on MA Public Lands in the Age of Climate Change

1. PUBLIC INPUT: To the general public carbon sequestration comes down to either manage or don't manage. The default position seems to recommend passive management which eliminates the modern-day economy of big heavy logging equipment that requires fast harvesting at the expense of soils and vegetation. But passive management avoids the problem of declining forest health due to climate change, herbivores, invasive plants, insects, and tree diseases. The CFI inventory program shows mortality increasing faster than growth on all public lands, which means, in the near future, mortality will be greater than growth on unmanaged public lands. What then? Without management only herbivores and invasive plants might be controlled and probably not enough to stem surging mortality.

2. EARLY SUCCESSIONAL VEGETATION: I agree with the report. Clear-cutting isn't necessary since succession happens naturally due to the destructive forces of climate change.

3. SALVAGE: Salvage should be determined on a case-by-case basis. What is left is more important than what is taken. But the taking must be carefully done with small, light equipment (<100 HP) and hand felling. with logging trails on less than 10% of the salvage area. Any proceeds from salvage operations should be spent on restoration planting that may require fencing.

4. OLDER FOREST: This phrase needs a definition. Much of our intact MA forest stands are in two-age classes originating from the massive harvesting at the beginning of the 20th century and from the 1938 hurricane. Is this old? On my own woodlot I have hemlocks in the 200–300-year-old age class that are slowly being eliminated by defects and insects. Trees decline in health for many reasons and the trees that avoid pathogens are usually on the best sites, rich mesic sites where carbon sequestration reaches the highest levels.

5. RESILIENCE: Working in MA forests for 60 years, I conclude that forest resilience, especially in the era of climate change, is achieved by carefully tending the forest through uneven-age silviculture providing more resources to the best performing trees. This means more light and moisture to the healthy, carbon sequestering trees by removing low-performing trees. It also aids the forces of plant succession.

6. EXEMPLARY FOREST PRACTICES: This phrase is often used by public land agencies, but without a definition. We need a thorough definition of this phrase. It is assumed that agencies that are not pressed for any significant revenue from the sale of forest products naturally maintain a high level of stewardship but that is not always the case.

7. FOREST SOILS: Soils are the foundation of the forest. We are learning more and more of how they allow the connections of trees and plants with fungi, bacteria and viruses for the benefit of all. However, the soils are sensitive, and heavy logging equipment that compacts, ruts and mixes forest soils destroys these connections, and, most importantly slows or restricts the movement of water through the soil forcing it to run over the ground.

January 24, 2024

Stephanie Cooper
Undersecretary for Environment
Executive Office of Energy and Environmental Affairs

By email to: guidelines@mass.gov

Dear Undersecretary Cooper,

The Partnership for Policy Integrity ("PFPI") appreciates the opportunity to comment on the *Recommendations for Climate-Oriented Forest Management Guidelines* (the "Report") prepared by the Climate Forestry Committee (the "Committee") as part of the "Forests as Climate Solutions Initiative" (the "Initiative"), and to provide our input as to how the Healey Administration can best implement the recommendations of the Committee.

We applaud the Committee's clear introductory framing, which states that **"disturbing the forests of Massachusetts as little as possible and allowing forests to grow and age through passive management is generally the best approach for maximizing carbon, ecological integrity, and soil health."** We similarly support the Report's recommendations that flow from this acknowledged reality.

As for how to implement the recommendations, PFPI's primary requests of the Administration are as follows:

- **Moratorium:** Continue the logging moratorium on state lands until new guidelines and rules are finalized by the relevant state agencies, and revise existing requirements for paused forest management projects to comport with such new rules and guidelines.

- **Water Supply Lands:** Take immediate administrative action to permanently prohibit timber cutting on Division of Water Supply Protection lands (except in extremely limited circumstances where there is a clear and scientifically documented threat to water quality or public safety). We note that several members of the Committee recommend such action with respect to state-managed forest lands around the Quabbin Reservoir (see pp. 40-41 of the Report). Given the decades of scientifically unjustified logging at the Quabbin and the associated public outrage, we believe that prioritizing making these lands around the Quabbin an "old growth forest of the future" – permanently free of timber cutting – would help to establish the public's faith in this Initiative.

- **Legislation:** Champion the pending legislation, H.4430 and H.904, which would greatly expand the acreage of forest reserves on state land and strengthen the definition of "forest reserves" to permanently prohibit timber harvesting in them. Until this legislation is enacted, take administrative action to implement the objectives of these bills.

The requested actions enumerated above squarely align with the Committee's core recommendations, and if properly and promptly implemented, these actions will go a long way towards achieving the central goals of the Administration's Initiative.

Key recommendations of the full Committee that we applaud:

- **Shift emphasis away from early successional habitat**, and increase emphasis on "late successional habitat and the development of old-growth forest characteristics."
- **Forgo "salvage harvesting"** in most circumstances, instead "leaving dead wood to realize the habitat quality and biodiversity benefits." ("The Committee was deeply skeptical of pre-salvage harvesting (removal before trees are affected by a pest or pathogen) and the notion that it is ecologically beneficial and indicated that it could only be justified in very narrow circumstances, such as trees causing a public safety hazard or a rapid response to a novel detrimental species occurrence.")
- "[A]rticulate [the Commonwealth's] rationale for active forest management on Division of Water Supply Protection lands." (This recommendation is underscored by the report's note that the "Division [of Water Supply Protection] acknowledged to the Committee that **active forest management is not necessary to maintain an abundant and clean water supply.**")
- **Regarding "resilience" as a management goal, "be more specific and transparent** when developing and proposing management actions by identifying the forest element or characteristic to be made more resilient, the disturbance to be addressed, and the way a proposed action improves the situation."
- Where harvesting is allowed, "employ practices that **reduce the disruption of forest soils** and the complex biodiversity of fungi and other organisms that inhabit them."
- **"Increase the Commonwealth's 2050 land conservation goal from 40% to 50%** of Massachusetts to be consistent with what the IPCC has called for."
- "Protect significant forest areas in western Massachusetts to **help create a large uninterrupted corridor of protected forest extending from Pennsylvania to Canada.**"
- **"Evaluate life cycle carbon emissions of forest practices and products** relative to other materials and processes and publish findings for Massachusetts forests."

Transforming these recommendations into enforceable rules and guidelines will be pivotal for the ultimate success of this Initiative, and for the fulfillment of Governor Healey's campaign promise to "develop and implement a science-based state forest management plan that accounts for the impacts of climate change on our forest resources and the role our forests can play in protecting the climate." Taken together, the recommendations provide firm scientific grounding for implementing stronger protections of public and private forested lands in Massachusetts.

Areas of Disagreement:

The commentary in the Report that PFPI disagrees with was generally represented as being the viewpoint of only a portion of the members of the Committee. In particular, we disagree with the stance of the Committee members who want to continue current levels of logging or even increase logging in Massachusetts. We agree with the viewpoint that passive management should be the default approach on publicly held forestland. We disagree with the push to source more wood in-state for local consumption, and we agree with the Committee members who cite "the moral imperative to address the climate emergency as superseding consideration of additional local harvest of timber."

Relatedly, we disagree with the notion that incentivizing harvesting wood products is consistent with climate goals, and we see such incentives as generally at odds with incentivizing passive management. In this regard, we appreciate the inclusion of this statement in the report: "A critical cautionary note is that increasing the use of long-lived wood products and substituting them for other materials will not necessarily increase stored carbon or reduce net emissions if harvest volume is increased. Some on the Committee also called for more impartial research on the carbon implications of substituting wood for other materials."

Conclusion:

In sum, PFPI finds the clarity of the unanimous recommendations of the Committee refreshing, and we urge the Administration to take the bold actions that logically follow from the science behind the recommendations highlighted above. We close with the following statement from the Report as a guiding principle:

> The Committee generally agreed that **passive management** confers greater increases in carbon stocks than active, and that **allowing forests to grow and age is typically best to maximize carbon storage. The Committee strongly agreed that carbon storage is typically greatest in old forests and disproportionately in the largest trees, and that Massachusetts forests can continue to accumulate carbon for many decades if undisturbed.**

Thank you for this opportunity to comment.

Sincerely,

Katy Eiseman
Policy Advisor
keiseman@pfpi.net

I followed the format of the form for general convenience, but since some comments were not going to fit on the form, I submit this version instead.

Karl Dziura
kmdziura@comcast.net
no affiliation
retired

Area(s) of Agreement? Please comment on sections of *The Report* with which you especially agree.

I agree with all of the statements made in support of the greatest degree of passive management, including the goal of designating 30 percent of Massachusetts forests as Reserves. Given the urgency of the climate emergency, it "is critical to avoid the carbon loss that results from active management given the steep reduction in GHG emissions that must occur in coming decades."

I agree with the following:
Forests should be kept as forests as much as possible.

"consideration [should] be given to new goals that place less emphasis on early successional habitat and more on late successional habitat."

"agencies be more explicit about their habitat goals, the rationale behind forest management projects, and their carbon and climate implications."

The ecological disturbance passage in the executive summary matches my view up to the point where the continuum is introduced, but not with the continuum in its current form.

" that passive management confers greater increases in carbon stocks than active, and that allowing forests to grow and age is typically best to maximize carbon storage."

Manage pubic water supplies passively. The Quabbin Reservation and the state lands in the vicinity in particular should be designated a Reserve.

I agree that nothing needs to be done to make forests more resilient.

I agree with the committee members who opposed timber harvesting in the belief that "the moral imperative to address the climate emergency as supersed[es] [the] consideration of additional local harvest of timber. They argued that Massachusetts' forests are better suited for removing and storing carbon, and other forests across the nation and around the world are better suited for producing forest products. They point out that Massachusetts forests are of an age and composition that is capable of accumulating large amounts of carbon out of the atmosphere in the critical decades between now and 2050 and beyond. In addition, they note that from a regional perspective, harvesting is the largest total source of emissions from forests relative to other disturbances."

Some emergency control of pests and pathogens is warranted.

6.Area(s) of Disagreement? Please comment on sections of *The Report* with which you especially disagree.

After considerable thought and research, I strongly oppose active management of state owned forest for habitat for climate change resilience, or both. The state has not made a convincing case the tradeoffs are worthwhile. Consideration should be given first to reducing CO2 emissions in an effort to alleviate the imminent demise of species worldwide like coral or the destruction of human communities. The United States bears the greatest responsibility for the climate crisis and we should not minimizing its impact when doing so will create more destruction and misery elsewhere than it will purportedly alleviate here.

I oppose the state's intent to actively manage state-owned forest land.

The continuum for considering salvage logging is worded to suggest that active management confers more benefits and should be written with more neutrality.

The ideas that "active forest management that focuses on enhancing ecological integrity and function is important to increase forest resilience to climate change and other stressors by enhancing forest structure complexity and species diversity to help forests transition to future conditions and ensure that forests reliably sequester carbon and maintain stocks" are based on insufficient scientific evidence and should not proceed on state-owned forest land unless and until convincing science supports these premises.

.**State Consideration: Please offer you comment for our consideration as we develop the state's response to these guidelines and their implementation by agencies**

All of the state's goals for active forest management can be accomplished by enhancing Chapter 61 incentives and enlisting private forest owners to either agree to active management or to make their lands Reserves.

It is not enough for agencies to be more explicit about their habitat goals, the rationale behind forest management projects, and their carbon and climate implications. *The Report* fails to outline a mechanism for public input, integration of public input, and its application. State agencies should be seeking citizen approval, not merely explaining what they intend to do. The science supporting active forest management greatly overstates the need and the arguments for logging frequently resort to generalizations that foster undue alarm. The insistence of state land managers that they can steward forests better than nature is belied by past management errors like widespread creation of Norway Spruce and Red Pine plantations that these same managers now want to remove. The record of forest management compares very unfavorably with the centuries of nature's successful self-governance.

I oppose the Commonwealth's imposition of "values and objectives beyond climate change for which it intends to actively manage forests, such as providing habitat for endangered species." In general, the science does not support active management and consequently it should not be utilized on state-owned forest land.

Updating the Forest Best Management Practices Manual is acceptable for use on private land.

Emergency control of pests and pathogens is not warranted unless it proceeds with careful case-by-case oversight that utilizes general public input. The idea that pests and pathogens can pose a threat needing emergency response is plausible, but state agencies given leeway have not always acted in the best interests of Massachusetts citizens.

Additional comments

Legislatively-mandated agency missions requiring logging do not support continuation of the practice, but indicate that the laws are out-of-date and in immediate need of revision.

Vague statements like, "Forests must be simultaneously managed for carbon sequestration and other benefits" fail to distinguish between private, private land trust, and state-owned forests. Designate all state-owned forests as Reserves and enhance Chapter 61 incentives to encourage private forest landowners to commit to either active management or Reserve status to obtain the incentives. Both options discourage development, identified correctly as the greatest loss of forest cover.

Manage pubic water supplies passively. The Quabbin Reservation in particular should be designated a Reserve along with the nearby DCR and DFW lands. In so doing, the state would create an invaluable, large, un-fragmented Reserve that would serve to protect the biodiversity that has, except for the period of land clearing during and after colonization, predominated in the Northeast.

Notwithstanding the *Climate Forestry Committee* makeup bias favoring logging for conservation and the frequent disagreement among the *CFC* members outlined in *The Report* regarding active versus passive management, *The Report* states that "The Committee generally agreed that passive management confers greater increases in carbon stocks than active, and that allowing forests to grow and age is typically best to maximize carbon storage." Contradicting this general agreement among the members of an otherwise contentious committee, the Commonwealth determined in *The Report* that it "has values and objectives beyond climate change for which it intends to actively manage forests, such as providing habitat for endangered species" (6). This statement is striking in that it contradicts the idea of forests as climate solutions, it overrides the The Committee's general consensus regarding the most effective way to utilize forests to reduce CO2 emissions, the Commonwealth's "values" do not align with those of most of Massachusetts citizens, and independent scientists dispute the value of the state's objectives throughout *The Report*.

The Report does mark a significant improvement in the state's handling of forest policy decision making in that it acknowledges the considerable body of science that opposes active forest management and *The Report* supplies some of the evidence citizens have requested for the state's determination to actively manage forests, though not enough to be convincing and without any opportunity for genuine public discussion. *The Report* comes very late in the process of examining forest policy in general and state-owned forest policy in particular, and the state's decision-making around increasing Reserves remains far too opaque and out of step with the preferences of its citizens. Ending state-owned forest logging does not interfere with any of the goals identified by the state and can contribute to meeting them more effectively if the state shifts its focus to private forest land.

Massachusetts' *Clean Energy and Climate Plans* identify the greatest source of forest loss: private land development. The committee for the *CFC Report* "unanimously agreed that maintaining forest cover is essential, recognizing that every acre of forest lost to conversion represents a loss of stored carbon to the atmosphere as well as a loss of future carbon sequestration" (5). The Commonwealth has, without general public input or sufficient scientific evidence, however, chosen instead to stimulate the logging industry in a way that limits the potential to reduce development of forest land rather than enlisting loggers in the effort to reduce it. The Commonwealth has decided to continue offering advantageous contracts to log state-owned forests. The state offers incentives to private landowners through Chapter 61 to log their land, providing private landowners a benefit for keeping their forests as forests and reducing forest loss to development. The state finds this policy important enough that from

the inception of the *FCSI*, it has planned to increase Chapter 61 incentives. However, the continuation of logging state forests reduces the incentive for loggers to approach landowners, inform them of Chapter 61 benefits, and secure agreements to log their land, and discourage development. Reducing development of private forested land is the most effective way to make forests climate solutions in Massachusetts. Ending subsidies to the logging industry in the form of state-owned forest land logging contracts offers the best opportunity for slowing loss of private forest land other than purchasing it. While incenting private forest land owners to designate their land as Reserves would be preferable, if the state insists on local production of wood, confine the production to private forest land.

In the "Executive Summary,-Guideline Implementation," the passage states "two means were suggested," but I only see one. It suggests agencies overseeing state-owned land management will proceed if the respective Commissioner states the recommendations are properly incorporated. First, state-owned lands should not be logged. Second, Based on my experience, I do not find the attestation of Commissioners sufficient. It raises a question for me: why has DCR Commissioner Arrigo taken no public role in this process? Given his absence, I am not confident in his assessments. I also do not think the trade-offs are justified in light of the climate emergency.

The Report articulates the need for increasing Reserves in Massachusetts, a position advocated by proponents of keeping our state-owned forest intact. In conjunction with focusing active management on private forest land, designating DCR and DFG land as Reserves offers the most direct and the simplest means of accomplishing the goal of increasing Reserves quickly to mitigate climate change. Subsequently the designation of Reserves on all state-owned forests should be codified with legislation. It has the added benefit of putting aside these lands for quiet enjoyment, solitude, and connection with nature for the citizens of the Commonwealth. Unfortunately, the state has determined to stimulate the logging sector and increase habitat fragmentation at the expense of most of its citizens. While the state has not made its plans entirely clear to the public, it is, and plans to continue, spending taxpayer dollars to expand conservation land. While this goal in itself is laudable, it should be undertaken only in addition to designating state-owned forests as Reserves. The state's plan to "Work […] with land trusts & municipalities to establish reserves on their holdings and across land held by multiple owners" is illogical if doing so substitutes for designating state-owned land as Reserves. Most of the private land trusts I have reviewed, including MA Audubon, The Nature Conservancy, The Franklin County Land Trust, The Berkshire Natural Resources Council, and the Hilltown Land Trust already agree with the state's active management policy and practice it on some or all of their lands. Asking them to change this policy and volunteer their lands for Reserves while the state continues to log state-owned forest land instead of designating it Reserves does not serve the citizens of Massachusetts well. If the option exists for Reserves to be under the control of the state versus under the control of private land trusts, keeping Reserves under state control and allowing for an opportunity for citizens to have a voice in their management serves the people of the state more effectively. The *FCSI* initiative expressed the state's approach to increasing Reserves as including private land trusts, municipalities, "and others," making no clear decision-making provision for the public. That part of the *FCSI* page has been removed, but *The Report* also lacks a clear decision making provision for the public. While *The Report* does state it will, in Appendix C focusing on Reserves, "Integrate and make public the best science, research, and management practices and provide detailed information on state forestry activities to increase transparency and enhance public knowledge" (68), it includes no clear decision making mechanism for the public. It is noteworthy that in *The Report* the state makes numerous statements about managers and the state providing information and explanations about climate data and project goals throughout its text, none of these statements defines a meaningful pubic decision-making role.

Regarding granting managers leeway in implementation of the guidelines, my experience with the state raises concerns about the implementation of these guidelines. Giving managers leeway with little oversight and no required process for receiving, accepting, and integrating citizens' reasonable expectations for the governance of their state-owned forests diminishes the likelihood that implementation of even these guidelines, which fall short of the wishes of thousands of citizens, will be implemented by EEA, DCR and DFG. Recommending that managers

articulate their purposes does satisfy the very minimal expectations citizens have for their government, but without providing a clear mechanism for receiving, integrating, and implementing citizen input, this leeway for managers is misplaced.

Additional Comment: Please offer any additional comments not covered by the previous questions.

Even though the "R" in DCR stands for the recreation thousands of Massachusetts citizens seek to enjoy peacefully in their state forests, the bulk of these forests in Western Massachusetts are designated as Woodlands subject to logging. *The Report* is silent on this ecosystem service despite its high priority among Massachusetts citizens. For the residents of Eastern Massachusetts, where Parks and Reserves mostly free of logging predominate, the state is much more receptive to citizen concerns. The DCR Stewardship Council invited Friends and Partners to present their ideas for shaping the DCR budget in May 2023. When those of us opposed to public lands logging asked to present to the DCR Stewardship Council Meeting, we were denied. As it stands, the creation and implementation of the DCR Landscapes Designation does not "assu[re] environmental equity and justice" for the citizens of Western Massachusetts (*The Report* 45) . In 2023, in the DCR *Ware River Watershed Public Access Management Plan Update*, citizens surveyed found that logging these state-owned lands is, to them, the activity chosen fourth as the most "Detrimental to Water Quality, Natural Resources/Wildlife, Public Enjoyment, or Abutters." The first three detriments were the environmental and ecological crimes of ATV use, motor vehicle use, and site degradation through dumping, camping, and campfires (https://www.mass.gov/doc/ware-river-watershed-public-access-management-plan-update-2023/download p.15). The *CFC Report* continues to ignore the concerns of the citizens who do not want the state-owned forests they visit logged and who do not want their natural heritage sold to unnecessarily benefit the logging industry.

WATER SUPPLY CITIZENS ADVISORY COMMITTEE
to the Mass. Water Resources Authority

485 Ware Road
Belchertown MA 01007
(413) 213-0454
fax: (413) 213-0537
email: info@wscac.org

January 24, 2024

The **Water Supply Citizens Advisory Committee** (WSCAC) thanks the Climate Forestry Committee (CFC) members for their hard work and the elaboration of the Climate Forestry Report. WSCAC appreciates the opportunity to comment on the final report during the public input session.

Established in 1978, WSCAC advises the Massachusetts Water Resources Authority (MWRA) and state agencies on water resource policy and watershed protection. WSCAC provides comments, information, advice, recommendations, and guidance as to the direction, intent, and execution of water planning and policy development. After reviewing the report, WSCAC would like to provide the following comments:

1. The assumption that the forest of the 21st Century, especially forest with passive management, will have the same or similar ability to sequester and store carbon as the Forest of the 20th century is not supported by the Continuous Forest Inventory Data (CFI) of DCR's Forestry (William VanDoren) and DCR/DWSP forests that include Woodlands, Reserves, and Park Lands that indicate that the forest is dying. Forest dying can also be illustrated by the recent die-off of 50,000 acres of oaks between Quabbin and Southeast Massachusetts, with 2,000 just on Quabbin Reservoir and 43.9% of natural deaths of gross growth in Quabbin and Ware watersheds between 2001 and 2020, as indicated in the report (Page 20).

2. Expanding on the Executive Summary, WSCAC understands the importance and necessity of debate in decision-making, but for the sake of precision and minimizing confusion, WSCAC suggests that it would be helpful if the committee spared the legislators and the public the display of some of the disagreements that occur among committee members in the report executive summary (see "Resilience" on page 6 and "Public Water Supply Management" and "Wood Production" on page 7). The experts should have come to a common ground after the contradictory debate incorporated in the body of the report (see pages 34 & 35 for "Resilience" and pages 41 to 44 for "Public Water Supply Management" and "Wood Production"). The Executive Summary should focus on providing recommendations and supporting elements to these recommendations deduced from the debate. With no specific recommendations, forest management will not change and will remain in the same position as when EEA Secretary Tepper introduced the "pause" in management.

3. WSCAC supports the continuous data collection and suggests that future forest carbon sequestration should be evaluated by agency staff and reviewed by EEA climate staff, considering a site-by-site approach based on existing characteristics, including current and future carbon sequestration potential, before proceeding with any forest management project in water supply watershed lands. Continuous data collection would provide a proper dataset so that the value of forest management can be weighed against potential carbon storage loss caused by management activities to better understand the costs and benefits of the management efforts.

4. WSCAC suggests that active management is necessary where maladapted species are present (red pine is used as an example in the Guidelines) to increase heterogeneity and enhance forest resilience, to provide wildlife habitat, or reduce the effects of-invasive pests or plants to the forest's health. Human intervention in the forest should consist of careful light thinning rather than clear-cutting, which stimulates invasive plants, diseases, and insects that weaken our forest. WSCAC suggests that the management should consist of tree

thinning using hand felling, removing unhealthy stands while leaving behind healthy saplings for advanced regeneration, and reducing the harvesting of old-growth forests.

5. WSCAC suggests promoting proven strategies to optimize forest growth and sustainability. CFC should elaborate on strategies proven to work elsewhere to enhance forest growth. Strategies may include but are not limited to tree planting and advance regeneration strategies and tactics. CFC can also suggest techniques to protect young sprouts from grazing, especially when herbivores are excluded from hunting and cannot be controlled (for example, the moose population in Quabbin). WSCAC believes that cost-effective techniques exist to ensure forest regrowth and the CFC should be more specific about what strategies to adopt. Agencies may act in good faith, but if clear guidelines are not provided (see "Resilience," "Public Water Supply Management," and "Wood Production" on pages 6 and 7), forestry management practices might not achieve much in using the forests to mitigate climate.

In conclusion, WSCAC is not opposed to forest harvesting; however, health or light cuts needed by forests to remain healthy should be emphasized, and some criteria should be taken into consideration to protect water resources and soil quality and to increase forest diversity of species and age classes to promote resilience, and carbon sequestration:

- Minimize the sizes of openings to avoid even-aged forests, preserve advanced regeneration and tree diversity for a more resilient forest, and reduce exposure of young sprouts to grazers,
- Restrict equipment size and weight of harvesting equipment to reduce or avoid soil compaction and damage to surrounding tree stands, and favor hand felling and small equipment usage suitable for small openings and soil health,
- Perform logging in a way that does not diminish the rate of carbon sequestration of the forest but increases forest resilience and preserves soil quality,
- Control wildlife populations to reduce herbivore grazing that causes serious damage to young tree sprouts. In addition to deer hunting, introduce moose hunting in watershed lands such as Quabbin and Ware watersheds or provide enclosures to keep large herbivores out of harvested areas until new growth is well-established.

WSCAC thanks you for this opportunity to comment on the Climate Forestry Report. The hope for WSCAC is to see the concerns presented above be reflected in the final report,

Sincerely,

Moussa Siri, WSCAC Executive Director

485 Ware Road

Belchertown, MA 01007

info@wscac.org

MASSACHUSETTS WATER RESOURCES AUTHORITY
Deer Island
33 Tafts Avenue
Boston, MA 02128

Frederick A. Laskey
Executive Director

Telephone: (617) 242-6000
Fax: (617) 788-4899
TTY: (617) 788-4971

January 23, 2024

Submitted via email at guidelines@mass.gov
Subject: Recommendations for Climate-Oriented Forest Management Guidelines

To Whom It May Concern,

The Massachusetts Water Resources Authority (MWRA) appreciates the opportunity to comment on the *Report of the Climate Forestry Committee: Recommendations for Climate-Oriented Forest Management Guidelines*. The guidelines will aim to provide science-based guidance on managing state lands and incentives for private landowners to maximize carbon storage, sequestration and overall climate resilience. MWRA supports the goal to make our forests more resilient to climate change and maximize carbon storage and sequestration, and looks forward to continued participation as State agency implementation plans are developed to ensure that forest management achieves the goals and benefits of multiple purposes simultaneously.

As noted in the report, the Climate Forestry Committee (CFC) was split on the role of active forest management in support of public water supply management and requested that the Commonwealth articulate the rationale for active management on Division of Water Supply Protection lands. For many decades the Department of Conservation and Recreation (DCR) and its predecessor agencies have maintained an active land acquisition and forestry management program within the lands owned for watershed protection around MWRA's source waters. MWRA provides drinking water from the Quabbin and Wachusett Reservoirs in central Massachusetts, with source waters located in the Quabbin, Wachusett and Ware River watersheds. MWRA views these programs as essential parts of MWRA's watershed and source water quality protection. The land acquisition program has resulted in an increase in the amount of protected (undeveloped) land. The current watershed forest management program is designed and operated for the specific purpose of maintaining a multi-aged and multi-class forest to protect MWRA's source water quality.

MWRA relies on the protective attributes of the forest as a critical component of its watershed protection efforts, and is judged annually by state and federal regulators on the ability of its protection efforts to reliably ensure high quality source water. MWRA is one of the few water systems nationwide with water sources that consistently deliver high quality water and are sufficiently well protected naturally such that the USEPA and MassDEP regulations allow MWRA to provide only primary disinfection of the water. This avoids the use of chemically enhanced filtration with its energy-intensive processes and associated carbon footprint.

January 23, 2024

The forestry program and overall forest management approach contained within DCR's 2017 Land Management Plan[1] satisfies MWRA's interest in assuring that DCR's forest management programs are building a resilient forest and protecting reservoir water quality in both the short term and the longer term and should be allowed to continue without change. These programs have resulted in an increase in protected (undeveloped) land which are an integral part of the overall watershed protection efforts. This has enabled MWRA to maintain its Filtration Avoidance determination from MassDEP and the US EPA since inception. This determination avoids not only the potential for a capital expense of hundreds of millions of dollars, but also a substantial increased use of energy and chemicals, and production of greenhouse gasses associated with a filtration plant. Additionally, a diverse and resilient forest allows for greater carbon storage.

MWRA looks forward to continued participation as the State develops plans to implement recommendations of the report.

If clarification is needed on any of these comments, MWRA would be happy to provide additional detail or respond to any questions. Feel free to contact MWRA's Director of Planning and Sustainability, Stephen Estes-Smargiassi at smargiassi@mwra.com.

Sincerely,

David W. Coppes, P.E.
Chief Operating Officer

Cc: Fred Laskey, Executive Director
Matthew Romero, MWRA Advisory Board Executive Director
Colleen Rizzi, Director of Environmental and Regulatory Affairs

1 ***Land Management Plan***, Division of Water Supply Protection, Department of Conservation and Recreation, 2017
www.mass.gov/doc/2017-dcr-division-of-water-supply-protection-2017-land-management-plan/download

January 24, 2024

Submitted via email at guidelines@mass.gov

Subject: Recommendations for Climate-Oriented Forest Management Guidelines

To Whom It May Concern,

The Massachusetts Water Resources Authority (MWRA) Advisory Board appreciates the opportunity to comment on the *Report of the Climate Forestry Committee: Recommendations for Climate-Oriented Forest Management Guidelines*.

To some, these comments may seem harsh, narrowly focused, and like they are out of step with the overall climate goals of the Commonwealth.

As the voice of the communities and ratepayers, the Advisory Board's primary goal and role is to ensure that the MWRA has the most pristine sources possible to ensure it can provide the best drinking water in the country to over three million individuals in the Commonwealth each and every day. The MWRA's member communities – through its ratepayers – have invested millions of dollars over the years and anticipate investing more in the future to continue safeguarding these source waters.

As noted in our initial response for comments during the "Forests as Climate Solutions" process, the Advisory Board supports and applauds the overall goal of optimizing carbon storage and sequestration through sustainable forest management practices as part of the Healey Administration's initiative. However, we believe this laudable goal must be balanced with the purpose of the previous, ongoing, and future investments that MWRA's ratepayers have made, are making, and will continue to make in the forests surrounding the reservoirs and watersheds that make up the MWRA's water supply.

The MWRA Advisory Board would like to highlight that the Climate Forestry Committee (CFC) was split on the role of active forest management in support of public water supply management, with some members advocating for active management to help create a more diverse forest, which can help to improve water quality by serving as a better "forest filter," others stating that active management wasn't needed to produce clean water, and still others arguing for no active management at all.

The Advisory Board reiterates its position that carefully considered and deliberately limited active management of the forests around the watersheds provides a better and more cost-effective filter for the waters that make their way into the MWRA's water supply. As the report notes, the Division of Water Supply Protection (DWSP) acknowledges that active forest management is not "necessary to maintain an abundant and clean water supply"; however, the Advisory Board's position is the same as DWSP's that careful cultivation of watershed lands is critical to maintaining a resistant and resilient forest and improves the natural filtration and overall water quality of MWRA's water supply.

In fact, it is this careful cultivation of the watershed lands, its forests, and its ecosystems that made the avoidance of building a costly water filtration facility possible decades ago, and the ongoing commitment to such a program continues to allow the MWRA to avoid the millions of dollars it would cost to build a filtration facility today. MassDEP has acknowledged over the years that the robust forest management program implemented by the DWSP in coordination

with MWRA and its staff continues to be critical to delivery of high-quality water and avoidance of costly infrastructure investments. Moreover, the construction and operation of a filtration facility would likely contribute to an increased production of greenhouse gases, energy consumption, and chemical use, not to mention additional costs for ratepayers.

The CFC has recommended that the Commonwealth more clearly articulate the goals of any active forest management, with specific reference to the DWSP-managed forests. On this point, the Advisory Board agrees, though perhaps with a slightly different perspective than the report's recommendations might suggest or intend. The Advisory Board would encourage DWSP to further demonstrate its commitment to a carefully considered and deliberately limited program of active forest management by more clearly delineating its overall goals, its plans and procedures for achieving said goals, and – perhaps most importantly – a consistent, frequent, and accurate reporting on the results of its program. As Peter Drucker's famous adage states: "You can't manage what you can't measure." The Advisory Board calls on DWSP to regularly report to the Water Supply Protection Trust the policies, procedures, and results of its forest management activities as they relate to the objectives of their land management plans and State climate solution goals.

The Advisory Board agrees with the CFC's finding that forest management is a critical strategy for mitigating climate change and protecting water quality. We also concur with the CFC's recommendation that the Commonwealth designate at least 10% of its forests as reserves and that these reserves be managed passively to preserve their carbon storage capacity and to protect water quality.

We have, however, clearly laid out our position that forests surrounding water supplies need to be viewed through a different lens, and that a "one size fits all" approach to forestry management cannot work in the Commonwealth given the critical role that the watersheds and the ecosystems and forests within them play in the supply of the pristine source water that over three million consumers have come to rely upon.

We urge the Commonwealth to adopt a more comprehensive approach to forest management that includes both passive and active management strategies. Active forest management is a proven and essential tool for protecting the water quality of the Quabbin and Wachusett watersheds. It ensures the long-term sustainability of vital natural resources, safeguards the delivery of healthy, high-quality water to current and future citizens of the Commonwealth, and delivers carbon sequestration.

We have appreciated the opportunity to participate in the ongoing process of the "Forests as Climate Solutions Initiative" and look forward to continued participation as the State begins to finalize and implement its goals and regulations to achieve them moving forward.

Sincerely,

Matthew A. Romero
Executive Director

cc: Fred Laskey, MWRA Executive Director
David W. Coppes, P.E. | MWRA Chief Operating Officer
Colleen Rizzi, Director of Environmental and Regulatory Affairs
John Sanchez, MWRA Advisory Board Chair

TO: Climate Chief Melissa Hoffer
Office of Climate Innovation and Resilience

FROM: Eleanor Tillinghast
Green Berkshires, Inc.

DATE: January 24, 2024

RE: Comments on Report of the Climate Forestry Committee

The Report of the Climate Forestry Committee reads as a last-ditch effort of the vanishingly small forestry industry in Massachusetts to survive in the face of overwhelming evidence that passive management of our state's forests is the cheapest, most immediate, and least damaging way to sequester vast amounts of carbon and effectively mitigate climate change.

This shouldn't be a surprise since the Committee that produced the Report has the word Forestry in its name. Five of the 12 members of the Committee are licensed foresters, and other members work for forestry departments in academia.

The Report identifies four strategies to reduce emissions and sequester carbon in forests and natural lands. Those should be re-ordered and modified, and the last one omitted altogether. This is the order of priorities that makes the most sense in light of the accumulated scientific evidence on forests as invaluable and irreplaceable carbon sinks in our age of radical climate change: (1) manage natural and working lands (NWL) to enhance carbon sequestration, (2) protect NWL to minimize land use conversion, and (3) restore NWL from degraded conditions. Utilizing NWL products that store carbon – meaning wood products – should be eliminated as a strategy because it's demonstrably ineffective toward the overarching goal of the Report and is basically intended to prop up the dying logging industry.

Over and over, sections of the Report start by acknowledging the benefits of sequestering carbon through passive management of our state's forests, and then specious arguments are inserted as to how forestry can be used to improve the carbon status of forests and other forest values. The comment "They agreed that forests should be considered not only for their carbon stocks and sequestration, but for a full range of societal benefits"[1] is just one example of such language peppering the report: The Report makes clear that societal benefits include wood products.

Dr. Richard Birdsey, a member of the Report Committee has stated succinctly elsewhere: "One of the largest threats facing mature and old-growth forests in the US is logging, which is a threat that humans can reduce instantly, simply by changing policy."[2]

Governor Healey should consider all favorable comments about forestry in the Report in the context of who participated in drafting it and who benefits from its support of forestry.

Here are a few concerns about the Report:

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[1] Report of the Climate Forestry Committee: Recommendations for Climate-Oriented Forest Management Guidelines, p. 9 of 70.

[2] (https://www.woodwellclimate.org/informing-us-forest-policy-with-science/

In Massachusetts, an estimated 219 people are employed in sawmills and wood production.[3] 378 people are licensed as loggers.[4] That is a total of 597 workers. Coupled with mining, employment in logging comes in dead last among industries in our state.[5] Those figures come from recent industry reports and the state's licensing board. The forestry industry uses various wildly inflated numbers, all of which should be dissected before being used in any official capacity.

The Report refers frequently to local wood products. That is misleading. According to an October 2023 industry paper titled Sawmills & Wood Production in Massachusetts, there are just 18 sawmill and wood production establishments in the entire state, none in Berkshire County.[6] I have spoken with truckers hauling logs and each one has said that his logs are headed to Canada. An article last year in a local paper quoted a logger as saying that his wood is sold in China.

The Report claims that since wood production on state land "is not pursued for financial benefit…state projects can afford to implement the highest and best strategies."[7] In fact, the state signs contracts with private loggers who most definitely are pursuing financial benefit at the least possible inconvenience to themselves. Throughout western Massachusetts are examples of logging operations on state lands that left damaged soils, invasives, and scarred landscapes in their wake.[8]

Contrary to the claims of the Report, reducing invasives through actively managing forests does not work. In my town, more than 50% of which is owned by the state, invasive plants have infiltrated the forests where logging has occurred. Invasives cannot be removed without applications of herbicides or repeated mechanical removal over many years. Herbicides shouldn't be used in ecologically sensitive areas. Mechanical removal requires years of funding and hands-on labor that state agencies don't do. Experts acknowledge that the best you can do is to avoid activities that might introduce invasives. Logging is the most direct pathway for invasives to move into forests.

The Report attempts to tie "resilience" with active forest management. We should have the humility to know that we can't predict what will result in true resilience once human interference is factored. We have seen that estimates from our top scientists and experts on future outcomes can be very wrong. State Senator William Brownsberger just wrote a devastating analysis of how much it will actually cost to decarbonize buildings; billions of dollars more than estimated.[9] Offshore wind development has proved to be vastly more expensive than expected.[10] Trying to manage for resilience is only as good as the latest accepted beliefs. Ecosystem services cannot be replaced.[11] Mistakes when dealing with mature forests are almost impossible to correct.

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[3] Sawmills & Wood Production in Massachusetts, US Industry State Report MA32111, IBISWorld, October 2023.
[4] https://www.mass.gov/doc/directory-of-licensed-timber-harvesters/download
[5] https://www.statista.com/statistics/551842/massachusetts-employees-industry/
[6] Sawmills & Wood Production in Massachusetts, US Industry State Report MA32111, IBISWorld, October 2023.
[7] P. 43 of 70.
[8] http://www.maforests.org/
[9] Mass. Decarbonization Roadmap radically underestimates costs - CommonWealth Beacon
[10] https://about.bnef.com/blog/soaring-costs-stress-us-offshore-wind-companies-ruin-margins/
[11] https://www.mass.gov/info-details/massachusetts-forest-action-plan

The Report also fails to account sufficiently for the impact to our forests of future demands from other mandated obligations that will result in forest conversion. According to the Massachusetts 2050 Decarbonization Roadmap:

> "Over the next 30 years, population-driven new development, mostly for housing, is expected to require approximately 125,000 acres of land. The necessary deployment of clean energy resources could potentially double that amount. Largely because trees are the dominant natural land cover in Massachusetts, as across the New England ecosystem, most, but not all, of this demand will result in "forest conversion," the clearing in whole or in part of currently wooded land to enable other social uses."[12]

In fact, the state's interim Clean Energy and Climate Plan for 2030 notes:

> To support widespread electrification, New England must likely deploy more than 40 GW of solar resources by 2050, which will exceed the total area of available rooftops in the region. In Massachusetts, even with maximal rooftop deployment far in excess of historic levels, that will require the installation of ground-mounted solar on approximately 60,000 acres of land in Massachusetts over the next thirty years. Breakthroughs in solar panel efficiency could potentially reduce that area significantly, but if other necessary clean energy resources such as offshore wind, inter-state transmission, or thermal capacity are constrained, the amount of required ground-mounted solar could potentially double.[13]

Together, the mandates for new housing and solar development could claim up to 250,000 acres of open space, much of which will be carved from forest land. This is a compelling reason to preserve the forest acreage owned by the state for passive management to enhance carbon sequestration as an offset to those conversions.

The Report notes that the "State Parks and Recreation Division has timber production as part of its statutory mission."[14] The executive and legislative branches have had no problem replacing old laws with new ones that more appropriately reflect current reality. Our recent spate of climate bills is testament to their ability to act quickly and decisively in the face of a global emergency. That law should be changed immediately. Foresters working for the state should be deployed solely to help private landowners manage their carbon resources rather than seek logging contracts on state and private land. More programs to reward landowners who preserve their forests, fields, and soils should be developed, funded, and promoted by Division staff. The state should use its extensive forests to show the benefits of passive management in enhancing carbon sequestration to meet the goals of our state climate laws. And we should characterize forest passive management as we do energy efficiency and memorialize in state law that preserving forestland is the cheapest, most immediate and effective way to decarbonize our atmosphere.

Regarding the third strategy listed as a priority at the beginning of this memo, to restore NWL from degraded conditions, I am not knowledgeable enough to comment on the difference between early

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[12] Massachusetts 2050 Decarbonization Roadmap, p. 75 of 92.
[13] Interim Clean Energy and Climate Plan for 2030 p. 41 of 53.
[14] Report of the Climate Forestry Committee: Recommendations for Climate-Oriented Forest Management Guidelines, p. 43 of 70

successional and late successional management for habitat restoration. I have observed, however, that the Division of Fisheries and Wildlife commits its own staff and financial resources to improving degraded lands for wildlife habitat. This has not been a priority that I have ever observed during my 38 years of interacting with the State Parks and Recreation Division.

In conclusion, over and over we are told that the climate emergency is the single most pressing issue of our time, and that each of us should expect some personal sacrifice. If that is true, the logic of saving an industry that directly employs only 597 people at the expense of preserving carbon-capturing forests throughout our state that will ensure a better future for millions of residents makes no sense and should be removed as a strategy in this Report.

To: The Executive Office of Energy and Environmental Affairs, Office of Climate Innovation and Resilience

From: Janet Sinclair Shelburne Falls, MA

I am pleased that this report made these recommendations for policies or guidelines state forests and privately owned forests:

At least 10% of the forests (of all ownerships) in Massachusetts be managed as reserves, and codified as such. Some Committee members suggested 30% of forested land as reserves.

Increase the Commonwealth's 2050 land conservation goal from 40% to 50% of Massachusetts to be consistent with what the IPCC has called for.

Some Committee members called for most conserved land to be managed like USFW at GAP-2- essentially a reserve.

All three state agencies should designate more land as reserves (DFW, DWSP,DCR).

Disturbing the forests of Massachusetts as little as possible and allowing forests to grow and age through passive management is generally the best approach for maximizing carbon, ecological integrity, and soil health.

There is no ecological rationale for salvage logging on state land.

Management of forests in the watersheds is not necessary for a clean water supply.

For private lands, incentives to protect forest land and manage it passively.

Place less emphasis on early successional habitat and more on late successional habitat and the development of old growth characteristics, including and especially on MFW land.

Access the extent to which early successional habit is, or could be continuously created or maintained, in all forested areas, create a goal for dedicated lands as early successional habitat, and this would likely lead to a reduced need to create more of it on state owned land. Consider the history of the forest landscape when considering these goals. Retain these habitats rather than create new ones.

Management is not necessary for resilience according to some members of the Committee.

Consider all natural land cover for goals, not just state land.

Provide more funding to the agencies.

Agencies manage a lot of their land passively; they should do so intentionally and state that.

Protect significant forest areas in western Massachusetts to help create a large uninterrupted corridor of protected forest extending from Pennsylvania to Canada.

Conserve forest blocks that connect existing reserves.

Reduce unnecessary forest land conversion via collaboration across state agencies and complementary polices, infrastructure investments, and other actions (e.g., solar facilities, powerlines, highways, housing, or other development). o Forest conversion on any given acre results in more carbon loss than harvesting on average, is more permanent, and also results in the loss of all other forest benefits.

Recognize that long lived wood products used to substitute for other materials will not necessarily provide long term carbon storage and this notion needs to be researched impartially.

Utilize, with appropriate updates to reflect circumstances unique to the other Divisions, the terminology, process, and criteria that DCR's Division of State Parks and Recreation followed pursuant to its Landscape Designations for DCR Parks and Forests: Selection Criteria and Management Guidelines to explore the identification of additional reserves.

Additional comments and recommendations.

1- I support a maximum amount of reserves based on the total land mass, not the number of forested acres. We advocate for 30% of all lands in Massachusetts as protected as GAP-2 by 2050. That would amount to a majority of acres forested land as reserves.

2- I disagree with –"When updating the criteria carefully consider designating actively managed properties, such as Myles Standish and Manuel Correllus state forests, separately from other reserves due to the level of active management used to maintain them." These forests are designated reserves and should remain so. All management activities should cease immediately except for in clear cases of public safety like a tree falling on a road or trail.

3- I don't understand this idea : "Enhance the ability of each agency to respond to and interact with the public, including environmental justice populations, to help avoid actions driven disproportionately by a small number of vocal advocates with special interests, often from well-resourced communities, which could lead to disparate outcomes and EJ inequities." How does expanding reserves and supporting forest and soil health on state land (as proposed by a vocal constituency) or demanding more harvesting (as proposed by a small number of vocal advocates with special interests) negatively affect EJ communities? This is a sad misuse of the intention of protecting EJ communities.

4- We should acknowledge that the public wants land in Massachusetts to be like our National Parks, and the public supports more reserves on all state lands.

5-Two bills in the legislature provide clear and simple ways to implement the ideas that we support in this report. We call on EEA and Governor Healey to ensure the passage of these bills.

H904- to give permanent protection as forest reserves for at least 30% of MFW lands, and to maintain that level in the future.

H4150- to give permanent protection as forests reserves including to urban parks that amounts to 415,000 acres, or about 8% of the Massachusetts land base.

6- We need to drastically reduce our consumption of wood products, reduce all consumption in general, and reuse and repurpose materials in order to have a healthier, more forested, and more sustainable planet.

7- Revise all current logging plans to implement the guidelines after they are finalized. Require the guidelines to otherwise be effective immediately.

Thank you.

From: Barbara Brousal-Glaser
To: Guidelines (EEA)
Subject: CFC Report on Forest Management in the Commonwealth
Date: Wednesday, January 24, 2024 11:35:48 AM

To Whom It May Concern,

I am a Newton resident and a member of the Trees as a Public Good Network and a Massachusetts voter and taxpayer. I am writing to comment on the CFC Report. I urgently state that climate considerations should be the main criterion for all forest and tree management decisions on public lands.

I agree with the following points of the CFC Report. (1) We should follow the climate-based science that all MA public forests should be minimally disturbed, passively managed, and PERMANENTLY PROTECTED FROM LOGGING so they are allowed to grow and age to maximize carbon sequestration, ecological integrity, soil health, and climate mitigation. (2) The state should buy more land for permanently protected (no-logging) reserves with a goal of reaching 30% of all MA forests in permanent reserves by 2030 and 50% by 2050. (3) The state should provide incentives for private landowners to permanently preserve forests and urban trees. (4) We should follow the climate-based science that we should NOT log in watersheds/reservoirs as it can endanger the public water supply. (5) The state should establish small forested lands in exurban and urban settings as permanently protected reserves.

I disagree with the following points of the CFC Report: (1) MA public forests should NOT serve any economic goals, for example for the wood industry or the land-trust companies. The majority of MA forests are privately owned; these privately owned forests can serve economic goals. (2) The state should NOT log in public forests, especially not in reservoir areas and watersheds. (3) The state should NOT log for early successional habitat and its associated species. We need to allow our mature forests to reach old-growth stages, where the climate benefits are much greater. (4) Incentives for private landowners to permanently preserve forests and trees should NOT replace permanent protection of all public forests.

I urge the state to prioritize the following considerations in implementing the CFC Report: (1) Permanently stop logging on public lands; all projects should be immediately reevaluated for climate (not economic) considerations. (2) Planting trees in urban areas is not sufficient; we need to *preserve* existing urban tree canopy, including making small permanently protected reserves, such as the NEMT Forest (13 acres) and the 4 acres of woods on Morton St. in Dorchester Boston. (3) The state should require *separate* measurement and reporting of greenhouse gas emissions from and carbon sequestration by agricultural lands, managed forests, and protected forests (no longer aggregating them as Natural and Working Lands).

Thank you for your consideration,

Barbara Brousal-Glaser

When responding, please be aware that the Massachusetts Secretary of State has determined that most email is public record a

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Barbara Brousal-Glaser

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From: Ashley Adler
To: Guidelines (EEA)
Subject: CFC Report
Date: Wednesday, January 24, 2024 2:34:14 PM

To Whom it May Concern,

I am a member of the Trees as a Public Good Network and a Massachusetts voter and taxpayer, and I am writing to comment on the CFC Report. Climate considerations should be the main criterion for all forest and tree management decisions on public lands.

I agree with the following points of the CFC Report. (1) We should follow the climate-based science that all MA public forests should be minimally disturbed, passively managed, and PERMANENTLY PROTECTED FROM LOGGING so they are allowed to grow and age to maximize carbon sequestration, ecological integrity, soil health, and climate mitigation. (2) The state should buy more land for permanently protected (no-logging) reserves with a goal of reaching 30% of all MA forests in permanent reserves by 2030 and 50% by 2050. (3) The state should provide incentives for private landowners to permanently preserve forests and urban trees. (4) We should follow the climate-based science that we should NOT log in watersheds/reservoirs as it can endanger the public water supply. (5) The state should establish small forested lands in exurban and urban settings as permanently protected reserves.

I disagree with the following points of the CFC Report: (1) MA public forests should NOT serve any economic goals, for example, for the wood industry or land-trust companies. The majority of MA forests are privately owned; these privately owned forests can serve economic goals. (2) The state should NOT log in public forests, especially not in reservoir areas and watersheds. (3) The state should NOT log for early successional habitat and its associated species. We need to allow our mature forests to reach old-growth stages, where the climate benefits are much greater. (4) Incentives for private landowners to permanently preserve forests and trees should NOT replace permanent protection of all public forests.

I urge the state to prioritize the following considerations in implementing the CFC Report: (1) Permanently stop logging on public lands; all projects should be immediately reevaluated for climate (not economic) considerations. (2) Planting trees in urban areas is not sufficient; we need to *preserve* existing urban tree canopy, including making small permanently protected reserves, such as the NEMT Forest (13 acres) and the 4 acres of woods on Morton St. in Dorchester Boston. (3) The state should require *separate* measurement and reporting of greenhouse gas emissions from and carbon sequestration by agricultural lands, managed forests, and protected forests (no longer aggregating them as Natural and Working Lands).

Sincerely,

Ashley Adler

From: Howard Birnbaum
To: Guidelines (EEA)
Subject: CFC Report
Date: Wednesday, January 24, 2024 3:39:15 PM

As a Massachusetts voter and taxpayer, as well as a naturalist and an economist, I am writing to comment on the CFC Report. My main point is that climate considerations should be the primary criterion for all forest and tree management decisions on public lands.

I agree with the CFC Report that we should follow climate-based science that suggests that MA public forests should be minimally disturbed and protected from logging. It would be a valuable public good for the state to buy more land for permanently protected reserves as well as provide incentives for private landowners to permanently preserve forests and urban trees. We should follow climate-based science to not log in watersheds/reservoirs to protect the public water supply. We also need small forested lands in exurban and urban settings permanently protected. Moreover, since MA public forests should not serve economic goals, the state should not log them to allow our mature forests to reach old-growth stages, where the climate benefits are much greater.

From: Barbara Fullerton
To: Guidelines (EEA)
Subject: CFC Report
Date: Monday, January 22, 2024 9:46:11 PM

I am a member of the **Trees as a Public Good Network and a Massachusetts voter and taxpayer** and I am writing to comment on the CFC Report. My main point is that climate considerations should be the main criterion for all forest and tree management decisions on public lands.

I agree with the following points of the CFC Report. (1) We should follow the **climate-based science that all MA public forests should be minimally disturbed, passively managed, and PERMANENTLY PROTECTED** FROM LOGGING so they are allowed to grow and age to maximize carbon sequestration, ecological integrity, soil health, and climate mitigation. (2) The state should buy more land for permanently protected (no-logging) reserves with a goal of reaching 30% of all MA forests in permanent reserves by 2030 and 50% by 2050. (3) The state should provide incentives for private landowners to permanently preserve forests and urban trees. (4) We should follow the climate-based **science that we should NOT log in watersheds/reservoirs as it can endanger the public water supply.** (5) The state should establish small forested lands in exurban and urban settings as permanently protected reserves.

I **disagree** with the following points of the CFC Report: (1) MA public forests should NOT serve any economic goals, for example for the wood industry or the land-trust companies. The majority of MA forests are privately owned; these privately owned forests can serve economic goals. (2) The **state should NOT log in public forests, especially not in reservoir areas and watersheds**. (3) The state should NOT log for early successional habitat and its associated species. We need to allow our mature forests to reach old-growth stages, where the climate benefits are much greater. (4) Incentives for private landowners to permanently preserve forests and trees should NOT replace permanent protection of all public forests.

I urge the state to prioritize the following considerations in implementing the CFC Report: (1) Permanently stop logging on public lands; all projects should be immediately reevaluated for climate (not economic) considerations. (2) Planting trees in urban areas is not sufficient; we need to *preserve* existing urban tree canopy, including making small permanently protected reserves, such as the NEMT Forest (13 acres) and the 4 acres of woods on Morton St. in Dorchester Boston.

Thank you for considering my opinion.

Barbara Fullerton

3 Winter St.
Weston, MA

David H Small
Naturalist
1542 Pleasant Street
Athol Massachusetts 013331
Dave@dhsmall.net

Executive Office of Energy and Environmental Affairs
100 Cambridge Street, Suite 1020
Boston, MA 02114

Dear Sir or Madam:

The Recommendations for Climate Oriented Forest Management Guidelines is an interesting exercise in looking at the state's forests and their role in carbon sequestration. Parts of the report I can concur with and others I feel are not taking the legislative goals of the individual agencies into account. Overall, it is my opinion that the goals of Endangered species/biodiversity for Division of Fisheries and Wildlife should be considered first and Carbon a clear second, but necessary discussion point in designing projects.

> The committee's statement that "Recognizing the significant carbon implications of current goals, especially for early successional habitat, the Committee recommended that as Executive Order 618 "Biodiversity Conservation in Massachusetts" is implemented, consideration be given to new goals that place less emphasis on early successional habitat and more on late successional habitat."
>
> Is an overreach and needs to be tempered with the actual science of species recovery. Climate policy needs to be calibrated to the biodiversity mission, not vice versa. It's apples to oranges, but how much climate impact is at stake versus how much biodiversity impact?

Several recommendations of the committee seem justified and reasonable in my experience.

> "Retain early successional habitat, rather than allow it to mature only to create it elsewhere, where wildlife biologists indicate that this approach creates equivalent habitat. Provide additional funding as this practice increases management cost."

The permanent management of early successional habitats in areas like the Crane WMA, Pine Hill WMA, Montague WMA, Muddy Brook WMA, and Birch Hill WMA, and Millers River WMA could provide long term habitat for Whip-poor-wills, Grasshopper and Vesper Sparrows, and invertebrates like the Frosted Elfin plus many plant species. The focus should remain on sandplain and barrens habitats with soil and/or bedrock characteristics are needed for rare species. The main difference in returning to the same acres more often is the funding of the projects. When removing mature trees to create habitat the revenue from the products produced offsets the additional work needed to bring the biomass to a reasonable level allowing management by mechanical mowing or prescribed fire. An increase in funding for the return to already managed sites would need to be provided.

I agree that electrical transmission corridors provide good early successional habitat in many cases. Depending on the footprint of the right-of-way narrow corridors may be sinks to early successional populations of birds. Small transmission corridors may be population "sinks" for target species. I would

suggest that in lieu of (wildly) asserting that energy infrastructure is a sufficient substitute for some of the habitat that needs to be provided, this should be as carefully documented as any other claims about natural area habitat. What are the parameters where energy infrastructure provides sufficient habitat? Who controls the habitat? Can the agency meet its mission while relying on external habitat?

An area not mentioned in the report which may have a higher success for some specific rare species would be partnering with owners of large “Cultural Grasslands” such as airports which under traditional DFW guidelines are not eligible for habitat management grants as the lands are not open to hunting. This approach could greatly increase the acres being managed for rare grassland/shrubland species at a relatively low cost. The program might include providing maintenance guidelines and incentives to maintain nesting habitat for grassland species.

The limitation of salvage and pre-salvage logging operations is a good start. There are several reasons to not salvage. If habitat is the goal salvage operations do not make sense. Downed or broken trees provide microhabitats. The decomposing of the material provides nutrients to the soil. Conversely salvage operations placing large machinery in the forest have several detrimental effects including damage to residual vegetation/regeneration, compaction of soils and interference with the natural subsurface hydrologic function of the forest soils.

Thank you for the opportunity to comment on the Climate Oriented Forest Management Guidelines

Dave Small
Member MA Natural Heritage & Endangered Species Advisory Committee
Retired - Assistant Regional Director DCR DWSP Quabbin and Ware River Watersheds
These are my personal comments and do not necessarily reflect those of any organization.

From: Morning Star Chenven
To: Guidelines (EEA)
Subject: Climate Forestry Committe Report - comments
Date: Monday, January 22, 2024 3:08:29 PM

To whom it may concern,
I am a member of the Trees as a Public Good Network and a Massachusetts voter and taxpayer and I am writing to comment on the CFC Report. **My main point is that climate considerations should be the main criterion for all forest and tree management decisions on public lands**.

I agree with the following points of the CFC Report. (1) We should follow the climate-based science that all MA public forests should be minimally disturbed, passively managed, and PERMANENTLY PROTECTED FROM LOGGING so they are allowed to grow and age to maximize carbon sequestration, ecological integrity, soil health, and climate mitigation. (2) The state should buy more land for permanently protected (no-logging) reserves with a goal of reaching 30% of all MA forests in permanent reserves by 2030 and 50% by 2050. (3) The state should provide incentives for private landowners to permanently preserve forests and urban trees. (4) We should follow the climate-based science that we should NOT log in watersheds/reservoirs as it can endanger the public water supply. (5) The state should establish small forested lands in exurban and urban settings as permanently protected reserves.

I disagree with the following points of the CFC Report: (1) MA public forests should NOT serve any economic goals, for example for the wood industry or the land-trust companies. The majority of MA forests are privately owned; these privately owned forests can serve economic goals. (2) The state should NOT log in public forests, especially not in reservoir areas and watersheds. (3) The state should NOT log for early successional habitat and its associated species. We need to allow our mature forests to reach old-growth stages, where the climate benefits are much greater. (4) Incentives for private landowners to permanently preserve forests and trees should NOT replace permanent protection of all public forests.

I urge the state to prioritize the following considerations in implementing the CFC Report: (1) Permanently stop logging on public lands; all projects should be immediately reevaluated for climate (not economic) considerations. (2) Planting trees in urban areas is not sufficient; we need to *preserve* existing urban tree canopy, including making small permanently protected reserves, such as the NEMT Forest (13 acres) and the 4 acres of woods on Morton St. in Dorchester Boston.
Thank you for preserving our forests for future generations! M. S. Chenven
6 Church St.

Erving, Ma. 01344

From: S. Anders
To: Guidelines (EEA)
Cc: Burney, Danielle (EEA)
Subject: Climate Forestry Committee Report / Implementation
Date: Monday, January 22, 2024 12:27:25 PM

To Whom It May Concern:

I am writing in response to EEA's call for public input on implementing the recommendations outlined in the Climate Forestry Committee's Report.

I very much appreciate the opportunity to comment. My response stems from personal experience with local impacts and interface with State Agencies through conservation-related committee and board roles. I'm not writing as a representative of these groups, however, but as an individual citizen who holds the belief that both passive and active forest management should be conditionally applied depending on forest characteristics and conservation goals. A local case may be illustrative as to how the Climate Forestry Committee's report can be implemented with State agencies in a beneficial and impactful way. Please bear with the backstory as I feel it's key to understanding some of my suggestions below.

MassWildlife recently proposed a project that involves converting the forestland at the Squannacook Wildlife Management Area into a 'Pine/Oak Barrens' habitat. As originally described, an initial timber harvest was planned to remove up to 70% of the overstory trees along a coldwater resource. The land was never used for agriculture and contains many old-growth characteristics including complex understory and exemplary natural biodiversity. It includes BioMap Forest Core. The harvest is to be followed by the use of prescribed fire, herbicides, and other forest management techniques to continue the conversion and management. The plan states that Native Americans historically used fire disturbance to manage this area. This is inconsistent with local knowledge of indigenous settlement in our town and archaeological accounts of Native Americans' use of fire in North Central Massachusetts. Trees slated for removal by MassWildlife within filter strips and the riparian buffer zone exceed general regulations and include riparian areas with highly erodible soils. ***Phase 1 is slated to take place on a 215-acre swath of land located in North Shirley and Townsend along Squannacook River, federally protected as a Wild and Scenic River, an Outstanding Water Resource, Coldwater Fishery, Area of Critical Environmental Concern, an NHESP-designated area, and Zone 1 and Zone 2 Wellhead Protection Areas.*** MassWildlife hopes to expand the project to include additional phases that would encompass more than 2,000 acres of land. Deforestation within the Squannacook River Watershed at the scale proposed approaches a tipping point where significant water quality impacts would be expected according to water resource experts. Disturbance in areas highly populated by deer and birds quickly become vulnerable to invasive plant infestations that will transport down the river and pose risk to abutting properties. Many key species slated for protection in this project are not truly indigenous to the area.

The Squannacook WMA has long been recognized as an area of high conservation priority. Benton

MacKaye, a forester and regional planner whose most widely recognized accomplishment was the conception of the Appalachian Trail, believed that while there were no 100% pure wilderness areas left in Massachusetts, the land along the Squannacook River was as close a sample of primeval forest as any that one might find in our region. MacKaye believed that the Squannacook Greenway, however, should be left in what he saw as its near natural state for the benefit of wildlife, recreation, and for the unique learning opportunities it could provide to the practice of forestry. As an analogy, he stated that just as a veterinarian needs to study healthy horses to provide care for sick ones, there is value in retaining healthy tracts of forest left in their wild state to inform the practice of forestry. He campaigned to protect this area and according to his biographer had the ear of the State since the late 1920's. Progress accelerated during the 1960's when the Middlesex County League of Sportsmen's Clubs raised money from thousands of local residents to purchase land and in 1966 donated 259 acres of land along the River in North Shirley and Townsend to Massachusetts Fish and Game. An excerpt from a Boston Globe article at the time read, "The 70 square miles will be managed by the division but won't be changed. It will look to your grandchildren just as it appears to you now and as it did to the Indians who gave the river its name." Local residents put their trust in the State Agency for the protection of this prized area.

The current oak woodland/barrens project moved forward without public input and completely lacked transparency. When I asked simple questions of the division or to the biologists, I often got no response, or something along the lines of "trust us, we have qualified experts working on this." I was directed to the agency's public website, which provided information ***inconsistent*** with the Notice of Intent submitted to the Towns of Townsend and Shirley. At a public meeting of the Nashua, Squannacook, and Nissitissit Wild and Scenic Rivers Stewardship Council, the Division Director announced to the group, "I do not need to share every detail with you and do not plan to." She also prohibited any type of study of the area that could potentially impact whether the project moves forward. Although I had been reassured that the project met the approval of the Coldwater Fisheries Director Adam Kauza, I later learned that at the time that he reviewed and approved the project, he was not aware that the Squannacook River was a federally protected Wild and Scenic River. He has been the most forthcoming of all the biologists involved (much appreciated) and noted to me that he did expect temperature impacts to the coldwater resource from the removal of vegetation but that *as the project was presented to him*, he thought the benefits would outweigh the costs. This was the most honest and forthcoming response I had received from anyone involved.

The lack of transparency and strong-armed tactics on a project that has a direct impact on climate resilience, water supply (Zone 1 and Zone 2 Wellhead protection areas), recreation, and historical preservation in our town has led to an erosion of trust with the public and definite resistance of both residents and local land conservation organizations to partner with the State in future land conservation efforts. I am very relieved to find a call for greater transparency and accountability, and a revision of habitat goals. When asked about greater public outreach, MassWildlife said they didn't have the time or staffing to do more, and plans for public site walks never materialized. **(1) Funding and policy improvements for public outreach and opportunities for public input are sorely needed for continued public faith and conservation partnerships, as well as (2) clear and consistent information on the goals and impacts of proposed projects, (3) an allowance for independent (neutral) study of impacts by stakeholders, committees, and boards charged with advocating for the protection of land and water resources, (4) clear and publicly available justification as to how proposed projects may or may not align with existing protections, climate**

goals, recreational, and historical values, (5) special designation of "no touch" areas with old growth characteristics that would be protected from excessive management or harvest, and (6) improving policy to allow local input on Forest Cutting Plans.

Forest Cutting Plans: In May of 2022 I attended a Massachusetts Association of Conservation Commission's (MACC) webinar on understanding Forest Cutting Plans. When a Forest Cutting Plan is submitted, the State does the assessment of wetland impacts and WPA compliance. The Q&A was revealing and primarily consisted of complaints about this process, mirroring some of our frustrations about the Squannacook WMA project. 1) Conservation Commissions (CCs) rarely have to read Forest Cutting Plans and as a result are often ill-equipped to understand them when they do; 2) project applicants are only required to submit plans to the CC 10 days prior to the start of tree harvest, if that 10 day period falls in between meetings, too bad; 3) DCR has really weak mechanisms in place for making sure CCs actually get the Forest Cutting Plan/people complained they are often not received at all and CCs are not informed about changes in land use during projects; 4) When a CC receives a plan for work on private property, they are not granted or guaranteed permission to enter the property for any type of confirmation or investigation of what's in the plan; 5) CCs who may have a far better sense of local wetland resources and potential impacts can comment on a plan (if they even receive it and can meet as a group) but do not have any final say. DCR assumes that because they're well-trained in forestry they're much better poised to make all these assessments themselves and can find input from others frustrating, often battling purely emotional/visceral reactions to tree harvest.

There's really no fair mechanism for local/community input. After all these frustrations aired at the presentation, the presenter (a State employee) suggested talking to people who could spearhead policy change.

Again, I'm extremely grateful for this opportunity to provide input. Thank you for all your time and effort to ensure the recommendations are implemented in a thoughtful and impactful way that will foster collaboration with other conservation groups and agencies, build public trust, and help ensure we meet climate resilience goals.

Sherry Anders, Town of Shirley Resident

From: Gene Chague
To: Guidelines (EEA)
Subject: Climate Forestry Committee recommendations
Date: Tuesday, January 23, 2024 9:11:02 PM

BERKSHIRE COUNTY LEAGUE OF
SPORTSMEN
150 Phelps Ave
North Adams, MA 01247

January 20, 2024

The Berkshire County League of Sportsmen (BCLS) is the umbrella organization for outdoor sportsmen's clubs in the Berkshires and represents approximately 4,000 members. Obviously, these clubs are primarily made up of hunters, fishers, trappers and other outdoor enthusiasts. After its Board reviewed Governor's Healey's proposed Forests as Climate Solutions, it was unanimously voted to make the following comments.

First, the BCLS Board applauds the Governor's efforts to decrease the emissions of carbon in our environment on a statewide level and her taking the time to create a board of experts to study what role our forests play in the control and sequestration of carbon. It welcomes and agrees with the recommendation to obtain more land for conservation purposes. It recognizes the importance of different types of habitat dealing with carbon and sequestration and trees for climate change and general environmental health.

Questions arise; however, with the Climate Forestry Committee's recommendation to reduce habitat goals for species dependent on young forests, shrublands, and grasslands on MassWildlife lands (WMAs) to increase carbon storage and sequestration. The BCLS views habitat biodiversity as just as important as climate, and maintaining diverse habitat through active management is the way to go. Natural processes are not fast enough to withstand the loss of wildlife. The BCLS is quite comfortable with the job that MassWildlife has
done to date in habitat management and biodiversity and wishes it to continue. Here in the Berkshires, we have seen the positive effects of its habitat management work on the Wildlife Management Areas (WMA), such as helping to bring back endangered species.

MassWildlife is made up of scientists who manage its lands based upon science and its WMAs are actively managed by qualified biologists. We agree with MassWildlife who recommends diversity of different kinds of wildlife habitat. They have signature forests as they serve a purpose, too, but they maintain a balance. Let's not forget MassWildlife has a statuary mandate to have biodiversity goals which encourage species richness and fortunately, they have qualified biologists to deliver.

Respectively yours
Board of Directors
Berkshire County League of Sportsmen

From: Gene Chague
To: Guidelines (EEA)
Subject: Climate Forestry Committee
Date: Friday, January 19, 2024 2:54:25 PM

Dear Sir or Madam

My name is Gene Chague and I write a weekly outdoor sports column for the Berkshire Eagle newspaper which is centered in Pittsfield, MA. In it, I reviewed Governor Healey's recommendation for Forest as Climate Solution. Here is what I wrote:Please consider these my comments.

The importance of our forests is finally hitting home – our very existence depends upon them. So we better get it right. This scribe applauds the Healey-Driscoll Administration for being proactive and taking the initiative to address the climate change issues and proposing enhanced climate-oriented forest management practices for Massachusetts.

However; the **Climate Forestry Committee** made one recommendation that bothers me. It recommended a reduction in habitat goals for species dependent on young forests, shrublands, and grasslands on MassWildlife lands (WMAs) to increase carbon storage and sequestration.

Does that mean that MassWildlife's program of clear cutting some sections of WMAs in order to encourage early successional growth, which provides food for wildlife, will be severely reduced or ended?

One would think that reducing this source of food for critters (deer, for example), will leave them no alternative but to browse heavily on young saplings which are generated from the mature trees in our forests. We have seen the effects of over browsing in the forests in the eastern part of our state and other areas. Over the years, as our forests grow older and trees fall or die off, there may not be any young trees to take their place, as they will have been previously chewed down. Such forests will eventually die off, which is contrary to the goal of enlarging our forest reserves.

January 24, 2024

Climate Forestry Committee
Executive Office of Energy and Environmental Affairs
Commonwealth of Massachusetts

Re: Comments to Report of the Climate Forestry Committee: Recommendations for Climate-Oriented Forest Management Guidelines

Dear Members of the Climate Forestry Committee,

Thank you for the opportunity to review and comment on the recently released report. The Berkshire Natural Resources Council (BNRC) is a regional land trust serving Berkshire County. Founded in 1967, BNRC has protected over 26,000 acres across the county, approximately half through Conservation Restrictions with over 100 landowners, with the other half being land that BNRC owns in-fee and manages for a diversity of conservation values and open space recreation purposes. In addition to the 26,000 acres BNRC holds a legal interest in, BNRC has helped protect tens of thousands of acres of land by assisting the Department of Conservation and Recreation, Department of Fish and Wildlife, as well as local, regional, and statewide conservation partners and municipalities.

BNRC has a keen strategic interest in furthering forest conservation and climate-oriented forest management, and we understand our role as a regional leader in these areas. We are largely supportive of the direction and goals of the administration and the CFC around landscape scale habitat protection for carbon sequestration and regional climate adaptation and mitigation. We recognize the urgency and the need to act to adapt to the changing climate. We know that planning for implementation of best management practices for forests in Massachusetts is a complex matter. The report from the CFC highlights the complexity and the challenges of managing land for different goals by different agencies and conservation entities and demonstrates the diversity of viewpoints among land managers when it comes to best practices to reach the climate goals set by policy makers. The report is the first baby step on the way to finding management practices to which such a diversity of interests can agree.

As one of the largest private landowners and land managers in Berkshire County we have an interest in seeing more nuance in how the CFC guidelines are further developed and exercised across the Commonwealth. We also have concerns that areas of disagreement between CFC members (e.g. Resiliency, Forest Management for Habitat, and Wood Production) creates inconsistency in how public and private land managers are to document and determine specific management strategies. There is so much more work ahead of us to arrive at useful and effective strategies.

Climate adaptation and mitigation at the local level benefits the Commonwealth and northeast region. Resilient landscapes require managing for a mosaic of forest age classes and structural characteristics, in order to support biodiversity, public health, and a strong local economy. We support a variety of management techniques, both passive and active, to meet the complexity of these goals.

Berkshire Natural Resources Council

309 Pittsfield Road, Suite B
Lenox MA 01240

413-499-0596

bnrc.org

We have concerns that the decrease in local wood products will externalize climate impacts of the Commonwealth at a time when we are trying to find opportunities for smart, sustainable, and affordable housing development. This decrease in local wood products will also economically impact our region, and without other changes to how DCR and others approach bespoke recreational development on state lands and forest reserves, these guidelines are asking our most rural communities to shoulder a significant financial burden for the Commonwealth.

Communities in western Massachusetts that support much of the state's forest land will be asked to contribute the most to the climate-oriented forest management. These municipalities should be compensated by the Commonwealth with specific, direct funding, well beyond the Pay In Lieu of Taxes programs that have been implemented in some places to help fund conservation efforts. A designated stream of income for the services these places are being asked to provide is necessary.

Respectfully Submitted,

Doug Brown
Director of Stewardship

From: Alisa Pearson
To: Guidelines (EEA)
Subject: Comment on CFC Report
Date: Wednesday, January 24, 2024 3:51:06 PM

We need mature forests, the older, the better: climate considerations should be the main criterion for all forest and tree management decisions on public lands.

MA public forests should NOT serve any economic goals, for example for the wood industry or the land-trust companies:

We need to permanently stop logging on public lands; all projects should be immediately reevaluated for climate (not economic) considerations.
(2) Planting trees in urban areas is not sufficient; we need to *preserve* existing urban tree canopy, including making small permanently protected reserves, such as the NEMT Forest (13 acres) and the 4 acres of woods on Morton St. in Dorchester Boston.
(3) The state should require *separate* measurement and reporting of greenhouse gas emissions from and carbon sequestration by agricultural lands, managed forests, and protected forests (no longer aggregating them as Natural and Working Lands).

From: Eric Hansen
To: Guidelines (EEA)
Subject: Comment on Report of the Climate Forestry Committee: Recommendations for Climate-Oriented Forest Management Guidelines
Date: Thursday, January 11, 2024 1:31:04 PM

Thank you for providing a platform for commenting on the Climate Forestry Committee's recently produced report. I was not able to submit my entire comment via the online portal, so I am emailing it here.

The draft "Report of the Climate Forestry Committee: Recommendations for Climate-Oriented Forest Management Guidelines" provides a lot of information and promotes important thinking about our forests. Many of the recommendations appear to be balanced and well thought out. One important thread that runs throughout I think misses the mark. Calls for dramatic change in the ways in which forests of the Commonwealth are managed indicates an implicit insinuation that current management goals and practices are either unimportant (or at least less important than they have been historically) or unsuccessful. As a Massachusetts Licensed Forester, I'd argue that they are neither, though there is always need for regular assessment and room for learning and improvement, perhaps now more than ever.

The climatic changes we are experiencing worldwide are not being caused by the ways in which Massachusetts forests are currently managed be it through passive or active management on private or public ownership. The same is true for losses of biodiversity. Forests that are actively managed with long term diversity of species, tree sizes, and age classes in mind tend to provide high quality habitat, enhance resilience, and continue to store carbon, while at the same time sustainably produce forest products that offset or replace the use of more carbon intensive products or fossil fuels. To that end, more focus in the report and in our on-the-ground reality should be given to responsible stewardship of forestlands. Passive management is an important part of that and should be done intentionally in places where it makes sense to do this, but climate-informed active management should be done on most of our lands where feasible and appropriate. Continued and enhanced monitoring is a critical part of any of these processes which the report does a good job of including for many stated issues.

There are a handful of points that I believe are important considerations to be given to final recommendations:

1. Forests are more than carbon and their management needs to reflect that.
2. We need to retain/maintain as many tools and approaches as we can to sustain the benefits that we all rely on (humans and otherwise) including but not limited to wood products.
3. Resilient forests are those that have diverse species, sizes, and age classes and

successfully implemented active forest management has those results in a near immediate time frame.

4. Vigorously growing trees are better able to respond to disturbances.
5. There are keystone species of vegetation that passive management does not provide suitable conditions for long-term (i.e., oak), the eventual decrease of which is a major concern for sustainability of our native insect and wildlife populations.
6. Passive management is important and should be done across the landscape but in areas where it makes sense to do it. This includes but does not necessarily need to be limited to areas that already show old forest characteristics.
7. Active management is also important and needs to be done in areas where it makes sense to do it. This includes but is not limited to sites with limited existing diversity and structural complexity, sites where there are exceptional existing diversity that will not self-perpetual in the absence of disturbance, and where the operation of equipment is suitable.
8. Maintaining our ability to be self-sufficient with what we can and know how to produce in an increasingly unstable world has long-term sustainability and security implications.
9. It is important to have publicly accessible (both physically and cognitively to lay audiences) demonstration areas that act as model forests so anyone can view and understand what is being done where and why. Increasing model (exemplary as the report states) management is important.
10. Decisions of what to do where (or what not to do where) should consider public opinion, but ultimately must be based on long-term goals and scientific data as opposed to current public opinion.

Viewing forests holistically means considering the suite of features and factors that our actions or inactions impact over the short and long terms. In other words, our forests store and sequester carbon, but they are more than carbon, and they are more than a solution to a changing climate. We focus solely on those features of their services to their detriment and the detriment of the myriad creatures and functions that rely on processes that responsible human stewardship can maintain or enhance. Thank you for providing a platform for comment.

Eric Hansen, Managing Partner
Ferrucci & Walicki, LLC
6 Way Rd
Middlefield, CT 06455
Phone: 860.349.7007
Fax: 860.349.7032
Email: eric@fwforesters.com
www.fwforesters.com

SAF
New England

January 23, 2024

Secretary Rebecca Tepper
Massachusetts Executive Office of Energy and Environmental Affairs
100 Cambridge St. 10th Floor
Boston, MA 02114

Dear Secretary Tepper,

The New England Society of American Foresters (NESAF) wishes to provide comments to the recently released *Report of the Climate Forestry Committee: Recommendations for Climate-Oriented Forest Management Guidelines*. Recognizing that the report is broad we have chosen to focus on certain concepts and recommendations on which we have positions and are important to our members. As support, our 2022 position, *Forest Carbon - Forest Management - Climate Change Solutions* is attached.

NESAF represents professional foresters and forestry in the six New England states including the Massachusetts Chapter. NESAF is a multi-state society within the Society of American Foresters (SAF), a national scientific and educational association representing the forestry profession in the United States. It is the largest professional society for foresters in the world. The mission of the Society of American Foresters is to advance sustainable management of forest resources through science, education, and technology, promoting professional excellence while ensuring the continued health, integrity, and use of forests to benefit society in perpetuity.

NESAF is strongly supportive of the Massachusetts Executive Office of Environmental Affairs (EEA) efforts in convening the Climate Forestry Committee (CFC) and efforts to provide forest management recommendations that focus on the role of forests in mitigating climate change. We note with disappointment, however, that little consensus was reached by the CFC on many important issues and potential climate mitigating forestry techniques. We therefore recommend that EEA exercise caution in crafting policy based on this report.

Keeping Forests as Forests

Our organization has stated that maintaining forests as forests is the most important tactic in carbon storage, sequestration and mitigating climate change. We applaud the CFC in unanimously recognizing that this is essential. We are also fully supportive of increasing permanent land conservation in the effort to further maintain forests as forests.

Habitat Management

It is laudable that the CFC recognized that habitat management, specifically for young forest conditions, is important in evaluating carbon stocks and sequestration. NESAF emphasizes that the benefits provided through implicitly managing for young forests are vitally important and should not be understated. Although carbon stocks are temporarily reduced in these areas, consider that carbon sequestration is significantly higher in regenerating forests. In a landscape approach to forest management, deliberate management for early successional habitat helps fulfill multiple ecological objectives.

Resilience

Actively managing forests for resilience using forest management tools is important in the face of a changing climate and the resulting disturbance events. An approach to introducing disturbance should balance regional historical evidence with novel approaches developed for improving forest resilience and carbon management under changing conditions. Introduced disturbance should promote complexity where warranted, and be grounded in science, such as the work promoted by the Northern Institute of Applied Climate Science.

Wood Production

NESAF encourages EEA to promote wood production in Massachusetts in general and on public lands in Massachusetts. The EEA data show that growth exceeds harvest significantly and the vast majority of wood consumed in the state is imported. Wood is an alternative to highly carbon intensive steel and concrete and can displace significant amounts of petroleum as a fuel. Managing for and harvesting wood from forests in Massachusetts can coexist with well planned climate forestry goals.

Forest Data

The CFC's complementary recommendations on maintaining and strengthening forest data is supported by NESAF. Although "forest data" is not directly mentioned in our attached position statement, NESAF contends that all appropriate forest management decisions are predicated on accurate forest inventory data. Our statements and position within *Forest Carbon - Forest Management - Climate Change Solutions* are referenced upon voluminous forest research and data. We are particularly supportive of communicating with "scientists to stay informed about best practices for climate and forest land management"; establishing new continuous forest inventory (CFI) on all public lands where needed and; expanding the data collected on all CFI plots. We strongly encourage examining current forest science and CFI data to develop balanced, passive and active forest management strategies.

In closing, the New England Society of American Foresters would like to emphasize that a science based, landscape approach that simultaneously manages for multiple forest structures can increase carbon

storage while providing the many other benefits afforded to us by managed forests such as diverse habitat, resilience and wood products.

Thank you for your consideration.

Sincerely,

Adam R. Moore, Immediate Past Chair of NESAF

From: Anderson, Kathi
To: Guidelines (EEA)
Subject: Comments on CFC Report
Date: Wednesday, January 24, 2024 3:15:40 PM

As a Massachusetts voter and taxpayer, I am writing to comment on the CFC Report. My main point is that climate considerations should be the main criterion for all forest and tree management decisions on public lands.

I agree with the following points of the CFC Report. (1) We should follow the climate-based science that all MA public forests should be minimally disturbed, passively managed, and PERMANENTLY PROTECTED FROM LOGGING so they are allowed to grow and age to maximize carbon sequestration, ecological integrity, soil health, and climate mitigation. (2) The state should buy more land for permanently protected (no-logging) reserves with a goal of reaching 30% of all MA forests in permanent reserves by 2030 and 50% by 2050. (3) The state should provide incentives for private landowners to permanently preserve forests and urban trees. (4) We should follow the climate-based science that we should NOT log in watersheds/reservoirs as it can endanger the public water supply. (5) The state should establish small forested lands in exurban and urban settings as permanently protected reserves.

I disagree with the following points of the CFC Report: (1) MA public forests should NOT serve any economic goals, for example for the wood industry or the land-trust companies. The majority of MA forests are privately owned; these privately owned forests can serve economic goals. (2) The state should NOT log in public forests, especially not in reservoir areas and watersheds. (3) The state should NOT log for early successional habitat and its associated species. We need to allow our mature forests to reach old-growth stages, where the climate benefits are much greater. (4) Incentives for private landowners to permanently preserve forests and trees should NOT replace permanent protection of all public forests.

I urge the state to prioritize the following considerations in implementing the CFC Report: (1) Permanently stop logging on public lands; all projects should be immediately reevaluated for climate (not economic) considerations. (2) Planting trees in urban areas is not sufficient; we need to preserve existing urban tree canopy, including making small permanently protected reserves, such as the NEMT Forest (13 acres) and the 4 acres of woods on Morton St. in Dorchester Boston. (3) The state should require separate measurement and reporting of greenhouse gas emissions from and carbon sequestration by agricultural lands, managed forests, and protected forests (no longer aggregating them as Natural and Working Lands).

Kathleen R. Anderson
17 Shattuck St.
Pepperell, MA 01463

From: Timothy Flanagan
To: Guidelines (EEA)
Cc: Tisa, Mark (FWE)
Subject: comments on Climate Oriented Management Guidlines
Date: Tuesday, January 23, 2024 1:28:02 PM

The members of the Massachusetts Natural Heritage & Endangered Species Program's (NHESP) Advisory Committee wish to comment on the Climate Forestry Committee's (CFC) Report regarding Recommendations for Climate-Oriented Forest Management Guidelines, which is part of the Healey-Driscoll "Forests as Climate Solutions" Initiative. Our comments are relative to those parts of the report that related to listed species management and protection according to the Massachusetts Endangered Species Act (MESA).

We acknowledge and support the initiative's goal to manage the Commonwealth's forests strategically for maximum carbon sequestration considering the on-going effects of climate change. The report does "*recognize that the Commonwealth has values and objectives beyond climate change for which it intends to actively manage forests, such as providing habitat for endangered species.*" CFC members concluded that state agencies use their recommendations to elevate climate and biodiversity to critical priority status through a combination of passive and active management strategies that balance the public's multiple needs and values.

From the perspective of the NHESP Advisory committee, forty percent of MESA-listed species require active management practices. Thus, we anticipate that if the Commonwealth manages for a healthy environment and protects its native wildlife, active management practices are necessary, especially about our changing climate. We have concerns that the CFC's report may be making recommendations that are too prescriptive, which can lead to conflicts across the government's agencies. For example, Massachusetts Executive Order 618: Biodiversity Conservation in Massachusetts recommends biodiversity conservation goals for 2030, 2040, and 2050 and strategies to meet those goals. However, the CFC report recommends that we "*place less emphasis on early successional habitat and more on late successional habitat*". Such a policy change may run afoul of habitat management options available under MESA.

Loss of globally rare habitats: sandplain grasslands, heathlands, and early successional barrens due both to development and succession have already resulted in the loss of much of this habitat in Massachusetts. Constricting management to later stage woodlands on formerly barrens habitats make it difficult to maintain established MESA species requiring this habitat or ultimately securing habitat so that they may be considered for delisting under the Act. The additional loss of early successional habitats will likely decrease biodiversity in Massachusetts, as species requiring or preferring these habitats may be lost.

We fully recognize the expertise of the staff of the Commonwealth's Natural Heritage and Endangered Species Program to carry out management decisions on listed wildlife species that balance habitat management objectives considering maximum carbon sequestration. It is our hope that legal requirements of MESA and the species recovery plans produced by NHESP staff are given priority as we continue to recognize the importance of abating climate change through carbon sequestration.

NHESP Advisory Committee members:
William Brumback, Tim Flanagan, Russ Hopping, Mark Mello, Wayne Petersen, Kevin Powers, Matthew Sisk, David Small.

submitted by: Timothy Flanagan on behalf of the NHESP Advisory Committee

From: Laura MacLeod
To: Guidelines (EEA)
Subject: Comments on Community Report
Date: Wednesday, January 24, 2024 11:20:45 AM

I am a member of the Trees as a Public Good Network and a Massachusetts voter and taxpayer and I am writing to comment on the CFC Report. My main point is that climate considerations should be the main criterion for all forest and tree management decisions on public lands.

I agree with the following points of the CFC Report. (1) We should follow the climate-based science that all MA public forests should be minimally disturbed, passively managed, and **PERMANENTLY PROTECTED FROM LOGGING** so they are allowed to grow and age to maximize carbon sequestration, ecological integrity, soil health, and climate mitigation. (2) The state should buy more land for permanently protected (no-logging) reserves with a goal of reaching 30% of all MA forests in permanent reserves by 2030 and 50% by 2050. (3) The state should provide incentives for private landowners to permanently preserve forests and urban trees. (4) We should follow the climate-based science that we should **NOT** log in watersheds/reservoirs as it can endanger the public water supply. (5) The state should establish small forested lands in exurban and urban settings as permanently protected reserves.

I disagree with the following points of the CFC Report: (1) MA public forests should **NOT** serve any economic goals, for example for the wood industry or the land-trust companies. The majority of MA forests are privately owned; these privately owned forests can serve economic goals. (2) The state should **NOT** log in public forests, especially not in reservoir areas and watersheds. (3) The state should **NOT** log for early successional habitat and its associated species. We need to allow our mature forests to reach old-growth stages, where the climate benefits are much greater. (4) Incentives for private landowners to permanently preserve forests and trees should **NOT** replace permanent protection of all public forests.

I urge the state to **prioritize** the following considerations in implementing the CFC Report: (1) Permanently stop logging on public lands; all projects should be immediately reevaluated for climate (not economic) considerations. (2) Planting trees in urban areas is not sufficient; we need to *preserve* existing urban tree canopy, including making small permanently protected reserves, such as the NEMT Forest (13 acres) and the 4 acres of woods on Morton St. in Dorchester Boston. (3) The state should require *separate* measurement and reporting of greenhouse gas emissions from and carbon sequestration by agricultural lands, managed forests, and protected forests (no longer aggregating them as Natural and Working Lands).

Prof.Laura MacLeod
Amherst resident

From:	Masino, Susan A.
To:	Guidelines (EEA)
Subject:	Comments on forests as a climate solution
Date:	Wednesday, January 24, 2024 6:08:19 PM
Attachments:	Quabbin STAC report comments Chivian 2013.pdf

To the Commonwealth,

Thank you for including these comments, below and attached, in the public record.

I am a scientist writing in response to the Forests as a Climate Solution report. Please accept this a few minutes late, I had an internet issue with the form and the formatting of this may be disordered.

First, there are a lot of good points in this current report. Thank you for recognizing the importance and power of nature. It is not optional, and it is for everyone.

Second, out of love for my home state, and for natural and working lands, highlight some concerns and provide suggestions that can help balance good forestry (and farming). There is a great need for unbiased and interdisciplinary approaches, natural systems and natural heritage, and cultural heritage and jobs.

Third, advocating for some natural forests is not "anti-forestry." Do not tolerate this dangerous and divisive narrative. We all need to be part of the solution.

First, the four overarching points:

(1) protect NWL to avoid land use conversion, (2) manage NWL to enhance carbon sequestration and resilience, (3) restore NWL from degraded conditions, and (4) utilize NWL products that store carbon and have lower emissions than alternatives.

This charge misses key points that relate to climate and community wellbeing - soil, full biological legacies, flood protection, public health, etc. I know there is a state mandate on carbon dioxide, but any "climate solution" that focuses primarily on atmospheric carbon dioxide is missing key variables and has little impact on the wellbeing of communities in Massachusetts. This is why we need interdisciplinary approaches for community lifelines that engage meaningful work and avoid motivated reasoning and conflicts of interest. That was my goal as cochair of this report:
https://portal.ct.gov/-/media/DEEP/climatechange/GC3/GC3-working-group-reports/GC3-Science-and-Technology-Working-Group-Final-Report-11-19-20.pdf

Related to this, the most fundamental need is to be specific and aspirational about ecological lifelines of natural land and water. This is our long-term solution, and a piece of land cannot serve all purposes – **multi-use is not compatible with prioritizing long-term natural processes.** A dedicated network of nature is needed to support everything else - including the productivity of working lands. It's like seed corn, and right now we need as much as possible, and every piece counts. This is a public trust issue.

Ten main concerns, and I underscore that each one is itself a public trust issue:

1. Cutting forests to make them climate resilient is an unproven experiment and/or based on a limited perspective.
2. Honest math shows that cutting forests adds carbon dioxide to the atmosphere in the next decades regardless of what happens to the wood. Cutting older forests is the most harmful.
3. Building more buildings does not help the climate, building reuse (and resource reuse) does.
4. Wood itself embodies more carbon than any other wood product or wood-based commodity.
5. We don't know if what we are doing is sustainable – it is a bulk estimate and based on insufficient data. Therefore we need to do as little cutting as possible and set forests aside where possible. The only way to do this is to define which forests are being cut and why; reduce, reuse, and recycle as much as possible; be as responsible as possible with what wood we do cut with high quality and downstream products. COLLECT LONG TERM DATA.
6. We should not allow exports of public wood. We are already subsiding this work in multiple ways, so should make it the best it can be.
7. Adopt the approach of "first do no harm." Again, collect more data. Set aside the lifelines, especially water resources with a natural buffer. We simply don't know enough, and nature should be the default because management quantifiably spreads invasives, creates more tick habitat, causes erosion, releases carbon, etc.
8. For community wellbeing we need to consider local climate stability, soil health, genetic diversity, biological legacies, mental health, natural heritage, flood protection. Where and how is expertise engaged on this holistically? Can this be a recommendation? These are some of the most precious and valuable services.
9. Sequestration is a futile mathematical cycle unless it results in additional accumulation. It should not be used in climate conversations unless this circular problem is revealed - it confuses the public.
10. Telling the truth about the critical importance of natural systems, the need to be responsible and thrifty with resources, etc., is an urgent public trust issue of the highest order. This is not against anyone, it is for everyone.

I attach a previous letter from Eric Chivian, MD re: the burden of proof. And I invite you to read this:

https://www.resilience.org/stories/2023-07-17/millan-millan-and-the-mystery-of-the-missing-mediterranean-storms/

Thank you for your work, I know this work is hard. It takes courage, and habits and social pressure are strong.
I hope Massachusetts can be a leader in doing the right thing, and the most important thing is to first do no harm.

Respectfully submitted,

Susan Masino

Note: I am experiencing extremely heavy email volume. Please don't hesitate to resend your reply.

Susan A. Masino, Ph.D.
Vernon Roosa Professor of Applied Science, Trinity College
Charles Bullard Fellow in Forest Research (2018-2019)
Harvard University

Stewardship Council

January 24, 2024

Stephanie Cooper, Undersecretary for the Environment
Executive Office of Energy and Environmental Affairs (EEA)
100 Cambridge Street, Suite 1020
Boston, MA 02114

VIA Email: guidelines@mass.gov

Re: **Comments on Report of the Climate Forestry Committee**

Dear Undersecretary Cooper and EEA staff:

The Department of Conservation and Recreation Stewardship Council supports the ambitious goals of the Forests as Climate Solutions Initiative and appreciates the work of the Climate Forest Committee to develop recommendations for climate-oriented forest management guidelines, based on the latest science, with the goals of increasing forest carbon storage and resilience to climate change. DCR is the largest owner of forest in the Commonwealth and bears the responsibility to steward the ecosystem and public benefits including climate that forests provide. Forest management is central to the mission of the agency. With that in mind, the Stewardship Council offers the following comments on the *Report of the Climate Forestry Committee: Recommendations for Climate-Oriented Forest Management Guidelines*.

We agree with the committee's statement that "[a]s shown in joint studies of The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the Intergovernmental Panel on Climate Change (IPCC), the three crises of climate change, biodiversity loss, and declining human equity and well-being need to be addressed simultaneously to avoid unanticipated and inadvertent consequences." As the largest forestland owner in the Commonwealth, DCR has a responsibility to focus on addressing these crises. In that context, we agree with the recommendation that DCR review its mission for consistency with Forests as Climate Solutions and other current policy issues, challenges, and opportunities, and ensure that agency goals and responsibilities include stewarding forests and other ecosystems, protecting and restoring biodiversity of all kinds, and assuring environmental equity and justice.

DCR's Division of State Parks and Recreation manages forests to support a range of ecosystem services including climate change mitigation, promotion of human health through improved air and water quality, forest health mitigation, conservation of biological diversity, quality forest recreation, and provision of local wood products. DCR’s Division of Water Supply Protection protects forests and drinking water resources in perpetuity for future generations. Given these

central elements of the agency's mission, we appreciate the committee's acknowledgement that "to achieve the statutory missions of the agencies, including protection of forests and wildlife, provision of quality recreation, production of local wood and provision of clean water and wildlife habitat, while also meeting statutory obligations to reduce carbon emissions, will require flexibility in application of the guidelines."

The Council understands “that the recommendations are intentionally general, to be considered and applied by state land managers as they utilize professional expertise to address specific circumstances” and that “Committee suggestions are not meant to be prescriptive, instead they are intended to allow managers to apply their knowledge and enable ongoing learning and adaptation.”

While we agree with the recommendation that "agencies be more explicit and transparent regarding land management objectives [and] articulate habitat/land cover and other goals in their guiding plans, to acknowledge when those goals are taking precedence, to explain their choices to pursue specific forest management projects, and to articulate the rationale behind forestry prescriptions for individual projects within the context of their division’s mission," we call attention to existing processes. DCR’s previous efforts in this area include Resource Management Plans, Forest Stewardship Plans, the work of the DWSP Scientific and Technical Advisory Committee, the Landscape Designations process, and the Forest Reserves Scientific Advisory Committee. We encourage refinement of these existing documents and processes rather than layering of additional processes to achieve these objectives.

Regarding Forest Management for Habitat and the committee's suggestion that "consideration be given to new goals that place less emphasis on early successional habitat," we would like to call attention to the Massachusetts Endangered Species Act, which reads, in part (MGL CH 131A Section 4), “All agencies, departments, boards, commissions and authorities shall utilize their authorities in furtherance of the purposes of this chapter and shall review, evaluate and determine the impact on endangered, threatened and special concern species of all works, projects or activities conducted by them and shall use all practicable means and measures to avoid or minimize damage to such species" and 321 CMR 10.05 which states, "Unless specifically required otherwise by statute, localities on state owned lands that provide habitat for state listed species shall be managed for the benefit of such listed species. Said agencies shall give management priority to the protection, conservation, and restoration of Endangered, Threatened, and Special Concern species occurring on state owned lands." (MESA should be listed in Appendix D with other Relevant Statutory Citations.)

Many state-listed species require early successional habitat. In fact, many of these species are in need of listing due to loss of this essential habitat. As less than 1% of DCR's forested land is actively managed each year (Table 1 in the report), we believe that carefully planned maintenance and creation of early successional habitat can be balanced with carbon storage goals. We urge that guidelines acknowledge the need to maintain the appropriate landscape-scale diversity of forested natural communities – including of varying species diversity, tree

density, canopy structure, and age classes – to support biodiversity, especially our listed species.

We agree with the recommendation that agencies develop metrics to evaluate their holdings for vulnerability to the effects of climate change, use these evaluations in the selection of sites and approaches for management, and assess the effectiveness of these approaches in addressing vulnerabilities.

We appreciated the committee's attention to the issue of excess deer browse and invasive species compromising forest regeneration. We urge attention and investment in efforts to comprehensively assess and strategically address these two stresses on our forests. However, we noted that there were very few mentions of fire in the entire document. Increased risk of wildfire is a great concern, exacerbated by climate change, that also requires a strategic assessment and response.

We strongly agree with the committee's support for efforts to reduce the rate of forest conversion to other uses, increase permanent conservation of forested land, and to enlarge forest reserves.
We also support recommendations for greater data collection to measure progress towards goals and to monitor the effectiveness of planned forest management activities. The frequent lack of consensus among committee members on specific management actions points to the need to expand research capacity among the agencies to guide management decisions. DCR's recent investment in a director of research will support a centralized research effort.

While the committee's scope may not have extended to urban and community forests, support for these forests is a key recommendation of the Climate Smart Practices List in Appendix A of the report – "Plant trees in urban and residential areas to add carbon stock as trees grow, and provide many local benefits to air quality, stormwater management, and human health and well-being." We strongly support efforts and investments to increase the extent and resilience of urban and community forests to sequester carbon and benefit all communities, particularly Environmental Justice and underinvested communities.

Carrying out this highly impactful increase in the pace of land conservation, forest management, data collection, research, and reporting will require increased agency capacity. We strongly encourage strategic increased investment in staffing, training, technology, and peer exchange to enable DCR and other state agencies to deliver on these ambitious and critically important goals.

Finally, we recognize the professionalism, expertise, and care with which DCR and MassWildlife staff manage our common wealth of forests to benefit the people and environment of Massachusetts.

Sincerely,
Jack Buckley
Chair, DCR Stewardship Council
CC: DCR Commissioner Brian Arrigo

From: Janet Sinclair
To: Guidelines (EEA)
Subject: Comments on the Climate Forestry Committee Report
Date: Sunday, January 21, 2024 1:33:01 PM
Attachments: CFC comments.docx

To: The Executive Office of Energy and Environmental Affairs, Office of Climate Innovation and Resilience

From: Janet Sinclair Shelburne Falls, MA

I am pleased that this report made these recommendations for policies or guidelines state forests and privately owned forests:

At least 10% of the forests (of all ownerships) in Massachusetts be managed as reserves, and codified as such. Some Committee members suggested 30% of forested land as reserves.

Increase the Commonwealth's 2050 land conservation goal from 40% to 50% of Massachusetts to be consistent with what the IPCC has called for.

Some Committee members called for most conserved land to be managed like USFW at GAP-2- essentially a reserve.

All three state agencies should designate more land as reserves (DFW, DWSP,DCR).

Disturbing the forests of Massachusetts as little as possible and allowing forests to grow and age through passive management is generally the best approach for maximizing carbon, ecological integrity, and soil health.

There is no ecological rationale for salvage logging on state land.

Management of forests in the watersheds is not necessary for a clean water supply.

For private lands, incentives to protect forest land and manage it passively.

Place less emphasis on early successional habitat and more on late successional habitat and the development of old growth characteristics, including and especially on MFW land.

Access the extent to which early successional habit is, or could be continuously created or maintained, in all forested areas, create a goal for dedicated lands as early successional habitat, and this would likely lead to a reduced need to create more of it on state owned land. Consider the history of the forest landscape when considering these goals. Retain these habitats rather than create new ones.

Management is not necessary for resilience according to some members of the Committee.

Consider all natural land cover for goals, not just state land.

Provide more funding to the agencies.

Agencies manage a lot of their land passively; they should do so intentionally and state that.

Protect significant forest areas in western Massachusetts to help create a large uninterrupted corridor of protected forest extending from Pennsylvania to Canada.

Conserve forest blocks that connect existing reserves.

Reduce unnecessary forest land conversion via collaboration across state agencies and complementary polices, infrastructure investments, and other actions (e.g., solar facilities, powerlines, highways, housing, or other development). o Forest conversion on any given acre results in more carbon loss than harvesting on average, is more permanent, and also results in the loss of all other forest benefits.

Recognize that long lived wood products used to substitute for other materials will not necessarily provide long term carbon storage and this notion needs to be researched impartially.

Utilize, with appropriate updates to reflect circumstances unique to the other Divisions, the terminology, process, and criteria that DCR's Division of State Parks and Recreation followed pursuant to its Landscape Designations for DCR Parks and Forests: Selection Criteria and Management Guidelines to explore the identification of additional reserves.

Additional comments and recommendations.

1- I support a maximum amount of reserves based on the total land mass, not the number of forested acres. We advocate for 30% of all lands in Massachusetts as protected as GAP-2 by 2050. That would amount to a majority of acres forested land as reserves.

2- I disagree with –"When updating the criteria carefully consider designating actively managed properties, such as Myles Standish and Manuel Correllus state forests, separately from other reserves due to the level of active management used to maintain them." These forests are designated reserves and should remain so. All management activities should cease immediately except for in clear cases of public safety like a tree falling on a road or trail.

3- I don't understand this idea : "Enhance the ability of each agency to respond to and interact with the public, including environmental justice populations, to help avoid actions driven disproportionately by a small number of vocal advocates with special interests, often from well-resourced communities, which could lead to disparate outcomes and EJ inequities." How does expanding reserves and supporting forest and soil health on state land (as proposed by a vocal constituency) or demanding more harvesting (as proposed by a small number of vocal advocates with special interests) negatively affect EJ communities? This is a sad misuse of the intention of protecting EJ communities.

4- We should acknowledge that the public wants land in Massachusetts to be like our National Parks, and the public supports more reserves on all state lands.

5-Two bills in the legislature provide clear and simple ways to implement the ideas that we support in this report. We call on EEA and Governor Healey to ensure the passage of these bills.

H904- to give permanent protection as forest reserves for at least 30% of MFW lands, and to maintain that level in the future.

H4150- to give permanent protection as forests reserves including to urban parks that amounts to 415,000 acres, or about 8% of the Massachusetts land base.

6- We need to drastically reduce our consumption of wood products, reduce all consumption in general, and reuse and repurpose materials in order to have a healthier, more forested, and more sustainable planet.

7- Revise all current logging plans to implement the guidelines after they are finalized. Require the guidelines to otherwise be effective immediately.

Thank you

From:	Tim Simmons
To:	Guidelines (EEA)
Subject:	comments
Date:	Thursday, January 25, 2024 3:45:55 PM

With apologies for late submission I offer the following.
A careful reading of the document reveals that some committee members maintain an excessively biased agenda.
This agenda is not informed by an understanding of existing procedures and policies guiding forestry practices for conservation in Massachusetts.
In 2016 a dry lightning event ignited fires throughout the Northeast. Understandably, none were allowed to burn and achieve their ecological outcomes. Failure to accommodate fire as a natural and anthropogenic process with a long and important history here is a glaring omission.
There are many aspects of habitat management and forestry that merit critical review. This exercise failed to address any of them.
Thank you for considering these comments.
Tim Simmons
Conservation Ecologist (Retired)

SCIENCE POLICY

A "Global Safety Net" to reverse biodiversity loss and stabilize Earth's climate

E. Dinerstein[1]*, A. R. Joshi[2], C. Vynne[1], A. T. L. Lee[1], F. Pharand-Deschênes[3,4], M. França[4], S. Fernando[1], T. Birch[5], K. Burkart[6], G. P. Asner[7], D. Olson[8]

Global strategies to halt the dual crises of biodiversity loss and climate change are often formulated separately, even though they are interdependent and risk failure if pursued in isolation. The Global Safety Net maps how expanded nature conservation addresses both overarching threats. We identify 50% of the terrestrial realm that, if conserved, would reverse further biodiversity loss, prevent CO_2 emissions from land conversion, and enhance natural carbon removal. This framework shows that, beyond the 15.1% land area currently protected, 35.3% of land area is needed to conserve additional sites of particular importance for biodiversity and stabilize the climate. Fifty ecoregions and 20 countries contribute disproportionately to proposed targets. Indigenous lands overlap extensively with the Global Safety Net. Conserving the Global Safety Net could support public health by reducing the potential for zoonotic diseases like COVID-19 from emerging in the future.

INTRODUCTION

Approximately half of Earth's terrestrial surface is considered to be in a natural or seminatural condition (*1*, *2*). How does this remaining habitat overlap with global conservation priorities and carbon storage requirements? This paper highlights sites of particular importance for biodiversity where additional conservation attention is needed, and other intact lands of high value for carbon storage and other ecosystem services. It also depicts the coincidence and disparities between terrestrial biodiversity and carbon storage priorities. This spatially explicit output, entitled the Global Safety Net for saving life on Earth, is intended to be a dynamic tool to support multilateral, national, and subnational land use planning efforts.

While the parallel crises of biodiversity loss and climate change have generally been approached separately, a key solution for two of the most pressing challenges of our time is the same: conserve enough nature and in the right places. Analyses designed to protect biological diversity have converged on the need to conserve and connect approximately half the Earth (*1*, *3*, *4*). In addition, several studies indicate that above 1.5°C in global average temperature rise, many ecosystems would be unable to adapt and, with increased biodiversity loss, could collapse (*5*). Nature-based solutions offer essential means to achieving the global climate objective of staying below 1.5°C (*6*–*8*). Achieving a future in which people and nature thrive is possible, but more ambitious conservation targets will be required (*9*, *10*).

To this end, a Global Deal for Nature has been proposed as a time-bound, science-based plan to be paired with the Paris Climate Agreement to save the diversity and abundance of life on Earth (*11*). This framework describes a set of science-based targets—organized by country and ecoregion—that would be required to conserve the vast majority of terrestrial plant and animal species. The Global Deal for Nature framework is mutually supportive of policies to address climate change. Scaling nature conservation offers fast and cost-effective measures to help stabilize the climate while providing cobenefits from ecosystem services such as the provisioning of clean air and water and the reduction in edge effects that could lead to future disease outbreaks.

The need for an ambitious global conservation agenda has taken on a new urgency in 2020 after the rapid spread of the COVID-19 virus. Global shifts in mammalian population trends reveal key predictors of virus spillover risk (*12*). Extensive deforestation in the tropics has led to humans coming into greater direct contact with vector-borne pathogens (e.g., Zika virus, which emerged from mosquito carriers in the Lake Victoria Basin forest-savanna) or via mammalian carriers that serve as viral hosts (e.g., HIV virus, which emerged from primates in the Northeast Congolian lowland forests). As important, achieving the area-based targets to protect all remaining intact and semi-intact terrestrial habitats would be an effective solution to reduce contact zones, helping to limit the chance of zoonotic diseases from affecting human populations in the future.

Here, using the Global Deal for Nature as a guiding framework, we examine where conservation of the terrestrial realm could be scaled to support biodiversity by securing additional lands to improve the resilience of ecosystems and secure terrestrial carbon stocks, both of which are essential if we are to have a chance of achieving the 1.5°C goal. The Global Safety Net explicitly avoids areas of concentrated human settlement, but it does not exclude resident human populations at relatively low densities in remote areas. We view this as a positive because, in particular, the sustained presence of indigenous communities within intact areas can have long-term benefits for both biodiversity and carbon storage (*13*).

This initial version of the Global Safety Net includes 11 spatial layers that, when combined, address expanded biodiversity protection and climate stabilization for the terrestrial realm. We also scope out a preliminary system of wildlife and climate corridors to identify the approximate amount of land that would be required to connect protected areas and intact landscapes. Besides mapping and assessing remaining natural habitat, we present tables of optimized contributions by ecoregion and by country required to maximize both biodiversity outcomes and land-based carbon storage. We also show how these targets may overlap with indigenous lands.

[1]RESOLVE, Washington, DC, USA. [2]University of Minnesota, Minneapolis, MN, USA. [3]Globaïa, Wellington, New Zealand. [4]EarthX, London, UK. [5]Google, Mountain View, CA, USA. [6]One Earth, Rockefeller Philanthropy, Los Angeles, CA, USA. [7]Arizona State University, Tempe, AZ, USA. [8]World Wildlife Fund, Hong Kong SAR.
*Corresponding author. Email: edinerstein@resolve.ngo

One potential application of the Global Safety Net is to inform the development of "common but differentiated" targets under the new post-2020 framework of the Convention on Biological Diversity (CBD). It could also help guide land-based mitigation in Nationally Determined Contributions made under the United Nations (UN) Framework Convention on Climate Change. The digital map of the Global Safety Net can be disaggregated by country, ecoregion, and indigenous territory, to shed light on overarching questions: How much does an ecoregion or country contribute to meeting global biodiversity targets? Do ecoregions identified as priorities for biodiversity protection also contribute disproportionately to carbon storage? What is the potential role of indigenous peoples' lands in supporting biodiversity protection and climate stabilization? Which ecoregions and countries will require the greatest investment in connectivity? At a local scale, the Global Safety Net can serve as a framework to align subnational land use planning efforts with global conservation and climate targets. The reverse is also imperative, as regional conservation planning efforts can replace various parts of the global layers where they are available.

Elements of the terrestrial Global Safety Net

We anchored the Global Safety Net with the current network of global protected areas (*14*). This network performs fairly well in representing sites important to narrow-range endemic vertebrates, yet gaps remain (*15*). The Global Safety Net fills in those gaps and targets other elements of biodiversity that need additional conservation attention. We built the Global Safety Net by mapping a comprehensive set of biodiversity elements to determine how much unprotected land needs increased conservation attention. To the extent possible, we included only remaining habitat and avoided agricultural lands. We then assessed where additional conservation measures are needed to achieve climate targets. Third, we created a preliminary network of wildlife and climate corridors to connect remaining natural habitat.

Target 1: Conserving the diversity and abundance of life on Earth

This target is designed to achieve, by 2030, conservation of unprotected biodiversity. For ease of conceptualization and presentation of results, these data layers can be logically placed into four clusters based on ecological factors, areal extent, or both. These include species rarity, distinct species assemblages, rare phenomena, and intactness. The first cluster, species rarity, is intended to capture species that are naturally rare—that is, they have narrow ranges, occur at low densities, or exhibit both conditions (*16*). The following are the six layers comprising the species rarity cluster: single populations of endangered species [Alliance for Zero Extinction sites (AZE); zeroextinction.org], an estimate of range rarity in vertebrates (*17*), ranges of threatened vertebrate species (iucnredlist.org), key biodiversity areas (KBAs) (*18*), vertebrate species distributions (*15*), and a new study of the spatial distribution of species rarity in plants (*19*). The distinct species assemblages cluster, intended to capture β-diversity—the turnover of plant and animal species communities with distance and along elevational or environmental gradients—includes remaining unprotected habitat of the biodiversity hot spots (*20*) and ecoregions of high β-diversity (*11*). Rare phenomena addresses unprotected landscapes containing rare global phenomena; here, we include areas containing the last intact large mammal assemblages of the terrestrial realm (including species such as large mammalian carnivores that are rare locally but range widely) (*21*). The fourth cluster, intactness, is composed of unprotected parts of the Last of the Wild in each ecoregion (*22*) and other wilderness areas (*23*) that provide potential macrorefugia for wildlife and representation of fauna.

Target 2: Enhancing carbon storage and drawdown

To identify important carbon stores, we used a map of total carbon biomass—a composite of above ground, below ground, and soil carbon (*24*). We first identified ecoregions above 215 metric tons (MT) of total carbon biomass per hectare, which is the median level across the 846 terrestrial ecoregions. We then overlaid the high carbon storage areas with areas selected under target 1 to determine overlap with important carbon reservoirs. Where coverage from target 1 was insufficient to meet climate objectives, we mapped additional areas containing high carbon stocks, designated as tier 1 climate stabilization areas (CSAs). We also mapped tier 2 CSAs, places that contribute to carbon storage and drawdown ranging between 50 and 215 MT of total carbon biomass per hectare. Ecoregions with median total carbon density per hectare of <50 MT were not included in this analysis.

Target 3: Wildlife and climate corridors: A scoping exercise

Connectivity is a time-bound issue of global consequence, yet most conservation plans fail to address potential climate corridors or interecoregional connectivity (*1*). Pressures on remaining natural habitats from land clearing and infrastructure development are so intense that options to maintain connectivity that exist today may disappear within a decade. Currently, only half of the 15.1% of the current roster of terrestrial protected areas are connected (*25*). If managed or restored to allow species movement, a system of comprehensive wildlife and climate corridors could connect the world's remaining intact habitats and enable adaptation in a rapidly changing world. To this end, we conducted the first global scoping exercise on connectivity and then checked against mapping studies of corridors delineated at national, ecoregional, and regional scales and published in the peer-reviewed literature or adopted by national agencies in various countries.

RESULTS

Target 1: Conserving the diversity and abundance of life on Earth

The 11 biodiversity layers underpinning the Global Safety Net add 30.6% (41,049,630 km^2) of unprotected land surface to the 15.1% currently protected (Table 1 and Fig. 1). This addition includes 14.6% for species-based approaches (clusters 1 to 3) and 16.0% for habitat intactness (cluster 4). Together with protected areas, these areas encompass 45.7% of the terrestrial realm where nature conservation should be a primary objective in the near term (Fig. 1). Areas identified for increased conservation attention under target 1 are concentrated in 45 ecoregions that contribute 10.9% to the 30.6% increase (Table 2) and 20 countries (Table 3 and table S3). The inclusion of some large, unprotected KBAs in a few nontropical forest ecoregions and countries, for instance, Sahelian Acacia Savanna and Russia, respectively, contributed their higher ranks in cluster 1 by size. Overall, conserving target 1 would increase representation by ecoregion across all major biogeographic realms and ensure continued storage of 1.36 million megatons of carbon (see target 2 below).

Widely used optimization approaches for global priority setting to map species rarity add only 3,047,787 km^2 or 2.3% of new area to the 15.1% already protected (Table 1 and Fig. 1). Overlaying the first global data layer of rare plant species distributions with rare and threatened vertebrates adds but 0.2% (198,231 km^2) to the 2.3%

Table 1. Elements of the Global Safety Net to expand protection of terrestrial biodiversity and stabilize climate beyond the current extent of protected areas and a scoping exercise to enhance connectivity.

Dataset name	Area	Total land surface	Est. total carbon (*24*)	Overlap with mapped indigenous lands (*26*)	
	(km^2)	(%)	(megaton)	(km^2)	(%)
Total land surface*	134,126,000	100.00	2,923,028	37,900,308	28
Global terrestrial protected areas	20,210,878	15.07	484,929	8,032,078	40
Unique contribution of currently unprotected lands†					
Target 1. Conserving the diversity and abundance of life on Earth (terrestrial)					
Cluster 1: Species rarity‡	3,047,787	2.27	75,638	526,739	17
Cluster 2: Distinct species assemblages	8,072,308	6.02	239,978	3,235,858	40
Cluster 3: Rare phenomena	8,414,171	6.27	442,625	4,092,873	49
Cluster 4: Intactness	21,515,364	16.04	602,157	7,157,106	33
Subtotal	41,049,630	30.61	1,360,399	15,042,327	37
Target 2. Enhancing carbon drawdown and storage					
Tier 1 climate stabilization areas§	2,337,236	1.74	82,878	309,899	13
Tier 2 climate stabilization areas‖	3,946,581	2.94	48,122	549,335	14
Subtotal	6,283,826	4.69	131,000	859,234	14
Total area to achieve targets 1 and 2	47,333,457	35.29	1,420,499	15,871,809	34
Total area for greater conservation attention within the Global Safety Net (including current protected areas (*14*))	67,544,335	50.36	1,905,428	23,903,887	35
Target 3. Wildlife and climate corridors: A scoping exercise¶					
Area required if targets 1 and 2 achieved	3,584,614				
Area required if targets 1 and 2 are not achieved (existing protected areas only)	5,705,206				

*On the basis of Earth's total terrestrial area excluding Antarctica. †Subtracts overlap with previous datasets. ‡All layers in cluster 1, except rare plant species, include a 1-km buffer around each site. §Includes ecoregions with median total carbon density above 215 MT/ha. ‖Includes ecoregions with median total carbon density between 50 to 215 MT/ha. ¶On the basis of corridor width of 2.5 km.

total for species rarity. While the amount of land is small, these areas are highly concentrated and irreplaceable for species conservation. Unprotected areas containing distinct species assemblages draw from 279 ecoregions that add 8,072,308 km^2 or 6.0% to the total of 30.6% for enhanced protection (Table 1 and Fig. 1). Rare phenomena (intact large mammal assemblages) contributed 6.3% (8,414,171 km^2) to the 30.6% increase.

The greatest extension by area to increasing global biodiversity protection comes from the inclusion of intactness (Fig. 1). These areas comprise over 21.5 million km^2 of unprotected habitat or 16.0% of the total land surface (Table 1). Grouped together, rare phenomena and intactness are primarily found in the taiga and tundra ecoregions in Siberia and Northern Canada. Russia and Canada and species-rich habitats in Brazil, the United States, Australia, and China contain almost 75% of the total area that could be added by targeting intactness while also conserving the most carbon (Tables 2 and 3).

Target 2: Enhancing carbon drawdown and storage through additional CSAs

We identified currently unprotected high-carbon areas that must be conserved to meet global climate targets. A by-product of conserving areas high in biodiversity value is that most, but not all such areas, also store the most carbon (Fig. 2). In ecoregions where the median total carbon density is above 215 MT/ha, a total of 29,247,979 km^2 of terrestrial area storing 1,331,834 megatons of carbon require increased conservation attention for carbon storage. Ninety-two percent of this area is already captured in target 1 (Fig. 2 and table S2), underlining the interdependence of carbon and biodiversity and the importance of these lands to achieve the dual goals

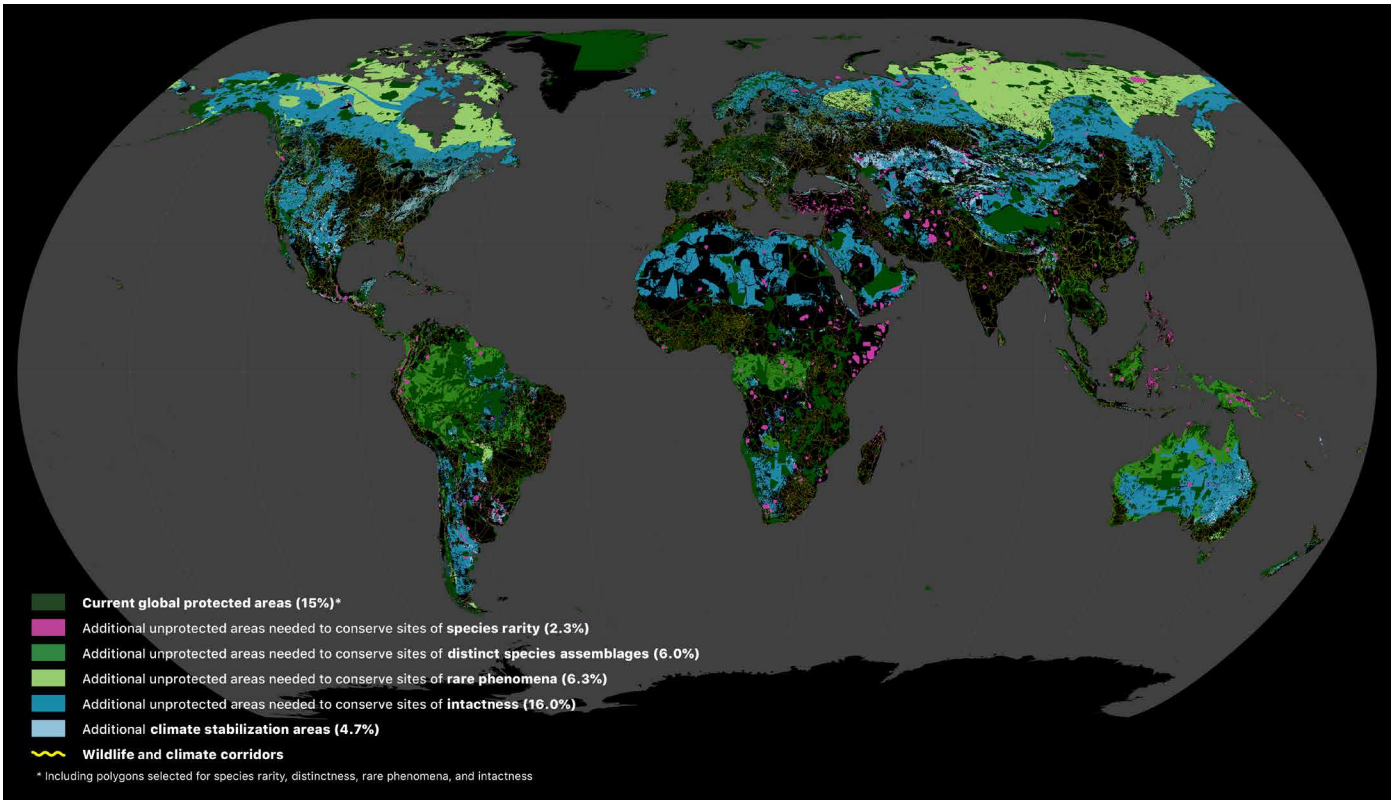

Fig. 1. Areas of the terrestrial realm where increased conservation action is needed to protect biodiversity and store carbon. Numbers in parentheses show the percentage of total land area of Earth contributed by each set of layers. Unprotected habitats drawn from the 11 biodiversity data layers underpinning the Global Safety Net augment the current 15.1% protected with an additional 30.6% required to safeguard biodiversity. Additional CSAs add a further 4.7% of the terrestrial realm. Also shown are the wildlife and climate corridors to connect intact habitats (yellow lines). Data are available for interactive viewing at www.globalsafetynet.app.

of biodiversity conservation and climate stabilization. To bridge the gap for adequate carbon storage beyond areas identified in target 1, the remaining 2,337,246 km^2 or 1.7% of Earth's land surface was selected as tier 1 CSAs in target 2 (Fig. 2).

In addition, we identified 3,946,581 km^2 of unprotected land, or 2.9% of Earth's surface, as tier 2 CSAs. Together, tiers 1 and 2 CSAs add 6,283,826 km^2 of currently unprotected lands, or 4.7% of global land area, to the Global Safety Net. These land areas store an estimated 131,000 megatons of carbon (Table 1). Indigenous lands (*26*) contribute extensively to carbon storage. Greater than 74% of all mapped indigenous lands (28,123,013 km^2) are tier 1 or tier 2 CSAs, and together, these areas store >931,000 megatons of carbon biomass.

Combined targets

Together, the two targets described above and currently protected areas that form the Global Safety Net cover 50.4% of the terrestrial realm as regions to enhance biodiversity protection and carbon storage (Table 1 and Fig. 1). Approximately 34% of the area in targets 1 and 2 is indigenous land (*26*). The overlap is particularly pronounced in high β-diversity ecoregions (41%; cluster 2), cluster 3 rare phenomena (49%), and cluster 4 intactness (33%). This includes many ecoregions in the tundra, boreal, tropical forests, and xeric biomes (table S1). We map results on a finer scale across five biogeographic realms—Neotropic, Nearctic, Afrotropic, Palearctic, and Indo-Malayan (Fig. 3, A to D). All mapped layers are available for online viewing at www.globalsafetynet.app.

Target 3: Wildlife and climate corridors: A scoping exercise

The scoping exercise on connectivity revealed the relatively small percentage of land that would be required to connect all intact areas. The percentage drops by almost half if the areas set aside for conservation under targets 1 and 2 are achieved. Connecting all current terrestrial protected areas via potential wildlife and climate corridors (using 2.5 km as an average corridor width) adds 5,705,206 km^2 or 4.3% of the terrestrial realm. Connecting proposed Global Safety Net areas (targets 1 and 2) would require substantially less total area for corridors to connect all intact terrestrial habitats if all targets are met. Connectivity varies greatly by biome, biogeographic realm, and within each realm. In general, Tundra and Taiga still retain excellent connectivity, less so in tropical forests outside the Congo Basin, Amazonia, and New Guinea, and xeric formations. The most fragmented biomes requiring extensive corridors to achieve connectivity are temperate grasslands, tropical dry forests, and tropical grasslands.

DISCUSSION

Interdependence of climate and biodiversity strategies and targets

Recent reports of tipping points and accelerating feedback loops related to climate change have profound implications for the need to scale nature-based solutions (*27*, *28*). Furthermore, new climate models highlight the important role of halting land use–driven

Table 2. Fifty ecoregions that contribute most to enhancing biodiversity protection and carbon storage through the addition of currently unprotected lands.

Ecoregion name	ID	Realm	Potential contribution of unprotected lands		Median total carbon density (MT/ha)	Est. total carbon (megatons)	Overlap with mapped indigenous lands	
			(km^2)	(% of land surface)			(km^2)	(% overlap)
Target 1: Conserving the diversity and abundance of life on Earth (terrestrial)								
Cluster 1: Species rarity			3,047,787	2.27		75,638	526,739	17
Sahelian Acacia Savanna	53	Afrotropic	64,794	0.05	32	207	12,873	20
Central Range Papuan Montane Rain Forests	139	Australasia	49,794	0.04	661	3,291	1,007	2
Sulawesi Montane Rain Forests	157	Australasia	45,021	0.03	520	2,341	31,674	70
Madagascar Humid Forests	17	Afrotropic	41,708	0.03	306	1,276	–	0
Mindanao-Eastern Visayas Rain Forests	247	Indomalayan	41,492	0.03	315	1,307	6,890	17
Registan-North Pakistan Sandy Desert	838	Palearctic	41,450	0.03	22	91	132	0
Southern Anatolian Montane Conifer and Deciduous Forests	804	Palearctic	40,482	0.03	151	611	–	0
Sulawesi Lowland Rain Forests	156	Australasia	38,542	0.03	389	1,499	17,016	44
Uruguayan Savanna	574	Neotropic	36,728	0.03	162	595	1	0
Northwest Andean Montane Forests	486	Neotropic	36,137	0.03	506	1,829	4,727	13
Taimyr-Central Siberian Tundra	781	Palearctic	35,932	0.03	549	1,973	29,660	83
Eastern Mediterranean Conifer-Broadleaf Forests	791	Palearctic	33,990	0.03	103	350	220	1
Northeast Siberian Taiga	714	Palearctic	32,581	0.02	504	1,642	502	2
Humid Chaco	571	Neotropic	31,479	0.02	196	617	4,572	15
Cerrado	567	Neotropic	30,602	0.02	128	392	250	1
Eastern Cordillera Real Montane Forests	460	Neotropic	30,133	0.02	470	1,416	7,509	25
Luzon Rain Forests	241	Indomalayan	29,630	0.02	257	761	3,099	10
Dry Chaco	569	Neotropic	29,224	0.02	151	441	2,896	10
Somali Acacia-Commiphora Bushlands and Thickets	55	Afrotropic	29,107	0.02	104	303	12,055	41
Napo Moist Forests	483	Neotropic	28,275	0.02	498	1,408	16,295	58
Albertine Rift Montane Forests	1	Afrotropic	27,559	0.02	286	788	1,697	6
Central Asian Northern Desert	817	Palearctic	27,436	0.02	71	195	–	0
Kazakh Steppe	732	Palearctic	27,040	0.02	246	665	–	0
Central Bushveld	38	Afrotropic	25,579	0.02	69	176	–	0
Taklimakan Desert	843	Palearctic	25,165	0.02	63	159	11,549	46
Subtotal of top 25 ecoregions			879,881	0.66		24,335	164,623	19
Cluster 2: Distinct species assemblages			8,072,308	6.02		239,978	3,235,858	40
Great Sandy-Tanami Desert	210	Australasia	485,000	0.36	44	2,134	404,287	83

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Ecoregion name	ID	Realm	Potential contribution of unprotected lands		Median total carbon density (MT/ha)	Est. total carbon (megatons)	Overlap with mapped indigenous lands	
			(km^2)	(% of land surface)			(km^2)	(% overlap)
Southwest Amazon Moist Forests	505	Neotropic	390,591	0.29	299	11,679	100,613	26
Northeast Congolian Lowland Forests	24	Afrotropic	335,644	0.25	270	9,062	46,102	14
Carpentaria Tropical Savanna	184	Australasia	302,470	0.23	72	2,178	154,446	51
Central Congolian Lowland Forests	3	Afrotropic	290,187	0.22	286	8,299	112,087	39
Northwest Congolian Lowland Forests	26	Afrotropic	280,551	0.21	304	8,529	81,550	29
Guianan Lowland Moist Forests	465	Neotropic	270,402	0.20	311	8,410	65,002	24
Borneo Lowland Rain Forests	219	Indomalayan	246,876	0.18	588	14,516	179,866	73
Madeira-Tapajós Moist Forests	476	Neotropic	237,641	0.18	273	6,488	21,861	9
Kimberly Tropical Savanna	186	Australasia	219,780	0.16	77	1,692	156,686	71
Subtotal of top 10 ecoregions			3,059,146	2.28		72,987	1,322,501	43
Clusters 3 and 4: Rare phenomena and intactness			29,929,535	22.31		1,044,782	11,249,979	38
East Siberian Taiga	710	Palearctic	3,191,009	2.38	432	137,851	2,296,934	72
West Siberian Taiga	720	Palearctic	1,101,626	0.82	955	105,205	852,961	77
Scandinavian and Russian Taiga	717	Palearctic	907,079	0.68	464	42,088	188,611	21
Northeast Siberian Taiga	714	Palearctic	893,387	0.67	504	45,027	635,724	71
North Saharan Xeric Steppe and Woodland	833	Palearctic	876,310	0.65	17	1,490	140,665	16
Canadian Middle Arctic Tundra	414	Nearctic	811,954	0.61	559	45,388	176,023	22
South Sahara Desert	842	Palearctic	772,701	0.58	11	850	396,380	51
Taimyr-Central Siberian Tundra	781	Palearctic	742,422	0.55	549	40,759	557,934	75
Eastern Canadian Shield Taiga	374	Nearctic	712,100	0.53	386	27,487	1,007	0
Canadian Low Arctic Tundra	413	Nearctic	683,279	0.51	563	38,469	162,758	24
Subtotal of top 10 ecoregions			10,691,867	7.97		484,615		51
Target 2: Enhancing carbon drawdown and storage								
Tier 1 climate stabilization areas			2,342,989	1.78		83,087	311,330	13
Sarmatic Mixed forests	679	Palearctic	252,482	0.19	422	10,655	–	0
Kazakh Steppe	732	Palearctic	178,348	0.13	246	4,387	–	0
West Siberian Taiga	720	Palearctic	105,467	0.08	955	10,072	56,333	53
Tian Shan Montane Steppe and Meadows	767	Palearctic	103,509	0.08	229	2,370	30,866	30
New England-Acadian Forests	338	Nearctic	99,898	0.08	345	3,446	445	0
Subtotal of top 5 ecoregions			739,704	0.55		31,227	87,643	12

emissions to meet global climate targets. Staying below the 1.5°C limit will require much of the world's remaining habitat—and a substantial amount of restored habitat in forest biomes—be put under some form of conservation by 2030 (*29*). Advances being championed under the two conventions responsible for biodiversity and climate—the Convention on Biological Diversity and the UN Framework Convention on Climate Change—must be accelerated if we are to protect the abundance and diversity of life on Earth and stabilize the

climate. A holistic solution is emerging that will accelerate both efforts: conserve at least half and in the right places (*9*, *11*). The Global Safety Net provides a pathway for using nature-based solutions to unite the two work streams.

The spatial coincidence of areas important for biodiversity conservation and carbon storage has long been suspected but is strongly confirmed here. The ecoregions and countries that score high for rare phenomena and intactness (clusters 3 and 4) conserve 1,044,783 megatons of carbon, equivalent to 35.7% of the total carbon present in natural habitats (Table 1). The gains in carbon storage achieved by adding protection of rare phenomena, a single layer, is comparable to carbon storage levels in the 15.1% of land that is currently in protected areas. By focusing conservation effort intensely on high β-diversity ecoregions, large mammal assemblages, intact areas, and wilderness, the payoff for climate stability is enormous.

The Global Safety Net framework presented here contrasts with the classic questions posed by conservation biologists: "How much is enough to save the biodiversity of each biome or ecoregion?" and "How do we protect all species globally in optimization approaches that conserve the greatest number of endemic or threatened species in the smallest area?" These concerns become less relevant under the extensive land conservation requirements of a 1.5°C climate pathway. The various global priority-setting approaches should be viewed as noncompeting: All are necessary to reverse biodiversity loss and stabilize the global climate system. A hopeful outcome of this framework and its implications for conservation is that every stakeholder and group can unite under the goal of staying below the dangerous threshold of 1.5°C in global average temperature rise, beyond which it would likely be too late to achieve most of the biodiversity goals set forth in the Convention on Biological Diversity.

Restoration

One overlooked area of research that should inform future iterations of the Global Safety Net is the restoration opportunities on degraded lands (*30*). These degraded landscapes could be restored to address both climate and biodiversity concerns. Further, reconnecting forest corridors in degraded lands could offset emissions that will occur before a moratorium on land-based emissions is reached. Focusing restoration efforts on degraded lands that can serve as wildlife corridors could help achieve other objectives, such as the Bonn Challenge (*31*). Similarly, massive tree-planting programs, if designed using native species and planted to restore corridors, riparian and coastal vegetation, and upper watersheds, could contribute to stabilizing climate and restoring connectivity.

Major opportunities exist for restoration of forests using native plants. Ecoregions such as the Atlantic Forest of Brazil, several forest ecoregions in Madagascar, and the Western Ghats of India are currently underrepresented in this version of the Global Safety Net, which is focused on protection of remaining habitat. Restoration opportunities should drive future iterations and allow for monitoring of recovery efforts. A prime example is the mid-elevation forests of Nepal, previously one of the more deforested and degraded ecoregions, where intensive community forestry programs have led to nearly doubling forest cover in 24 years (*32*), increasing carbon stocks from 213.42 to 502.03 megatons.

Indigenous lands

The overlay of mapped indigenous territories with spatial targets 1 to 3 reveals an extensive overlap of 37% and underscores the central role that indigenous peoples and their lands play to preserve biodiversity and regulate Earth's atmosphere (*26*, *33*, *34*). Another observation is echoed by other conservation biologists who have examined maps of indigenous lands and global biodiversity priorities: A 30% area–based target for protection by 2030, as advocated by many groups to the Convention on Biological Diversity, effectively already exists when accounting for indigenous lands, should effectively conserved lands be formally acknowledged by governments as other area-based effective conservation measures (OECMs) (*35*). In short, the "30 × 30" target is far less ambitious when viewed through this perspective. Many conservation organizations, indigenous peoples, and local communities have called for an area-based target of "at least 50%" under the Convention on Biological Diversity. Explicit in these calls is to allow for the protection of the land rights and traditional management practices of communities most at risk to food insecurity, the negative impacts of land degradation, and climate change.

Can a Global Safety Net be created in time?

There are reasons to support the notion that a Global Safety Net encompassing approximately 50% of land area is achievable. Addressing indigenous land claims, upholding existing land tenure rights, and resourcing programs on indigenous-managed lands could help achieve biodiversity objectives on as much as one-third of the area required by the Global Safety Net. Simultaneously, this focus would positively address social justice and human rights concerns. In addition, economists are examining pathways for scaling conservation and restoration across all land jurisdictions (*36*). New research from the World Economic Forum ties half the world's gross domestic product—$44 trillion dollars—directly to nature and its services (*37*). The recent COVID-19 crisis has demonstrated the ability of the world's governments to mobilize trillions of dollars, and there are a number of proposals emerging to tie environmental restoration and climate response to economic recovery. CSAs offer one framework to move beyond the incrementalism of protected area designation over the past couple of decades. Last, a key finding of this study is that species closest to the brink of extinction or where rare species concentrate could be protected by an addition of only 2.3% more land area if allocated to the right places and well managed. That target should be achievable within 5 years.

The connectivity analysis offers a template to build from and engage local and regional entities in designing programs centered on restoring connectivity. This effort could merge with global habitat restoration and native tree-planting initiatives now under way. Investments needed for the establishment and management of additional protected areas and restoration of degraded lands, while substantial, are small compared with enormous fossil fuel subsidies. The estimated $4.7 trillion per year in fossil fuel subsidies are expected to decline as the Paris Climate Agreement is implemented, making government resources available for restoring, rather than destroying, our global climate system.

Today, the emergence of a strong advocacy for science-based targets offers hope of an accelerated timeline for delivery far faster than we might expect. National-level leadership to champion the Global Safety Net and, by extension, the Global Deal for Nature, could ideally come from the list of 20 countries where increased conservation attention is most needed (Table 3). Russia, Brazil, Indonesia, and the United States have an outsized role to play and abundant internal resources to do so. Leadership could also come from

Table 3. Top countries that contribute most to enhancing biodiversity protection through the addition of currently unprotected lands (target 1).

Country name	Potential contribution of unprotected lands		Overlap with mapped indigenous lands	
	(km^2)	(% of land surface)	(km^2)	(% overlap)
Cluster 1: Species rarity	3,047,787	2.27	526,739	17
Russia	209,303	0.16	85,912	41
Indonesia	167,755	0.13	81,534	49
Turkey	154,675	0.12	–	0
China	128,963	0.10	36,686	28
Argentina	119,732	0.09	32,961	28
Brazil	114,098	0.09	911	1
Philippines	107,095	0.08	19,008	18
Kazakhstan	104,034	0.08	–	0
Australia	99,955	0.07	41,080	41
Papua New Guinea	99,468	0.07	–	0
Subtotal of top 10 countries	1,305,078	0.97	298,093	23
Cluster 2: Distinct species assemblages	8,072,308	6.02	3,235,858	40
Australia	1,580,457	1.18	1,033,319	65
Brazil	1,025,312	0.76	42,350	4
Indonesia	810,872	0.60	524,929	65
Democratic Republic of the Congo	726,843	0.54	188,665	26
Colombia	542,762	0.40	257,344	47
Peru	449,408	0.34	169,896	38
Papua New Guinea	266,264	0.20	91,577	34
China	264,675	0.20	10	0
Bolivia	229,561	0.17	63,642	28
Guyana	154,616	0.12	21,539	14
Subtotal of top 10 countries	6,050,770	4.51	2,393,273	40
Clusters 3 and 4: Rare phenomena and intactness	29,929,535	22.31	11,249,979	38
Russia	9,715,587	7.24	6,703,659	69
Canada	6,711,800	5.00	557,055	8
Australia	2,143,745	1.60	1,149,499	54
United States of America	2,116,096	1.58	240,141	11
China	1,191,623	0.89	707,847	59
Saudi Arabia	858,089	0.64	281	0
Algeria	715,269	0.53	260,128	36
Libya	660,683	0.49	87,753	13
Argentina	568,778	0.42	128,449	23
Brazil	512,384	0.38	10,957	2
Subtotal of top 10 countries	25,194,055	18.78	9,845,767	39

countries such as Costa Rica, Peru, Namibia, and others, creating their own national safety nets that incorporate the landmark conservation plans of each nation's constituent ecoregions, including adjacent marine ecoregions. In the United States, one could envision a California Safety Net or Maine Safety Net built from enhanced terrestrial and marine ecoregion plans. The Global Safety Net could also inform country-scale conservation and development plans, supporting UN conventions through an overlap analysis with outputs of the Country Emissions Gap Reports (*38*).

Similar to the Paris Climate Agreement, and in alignment with the Sustainable Development Goal 15 (SDG15), a Global Deal for Nature calls for common but differentiated contributions by every

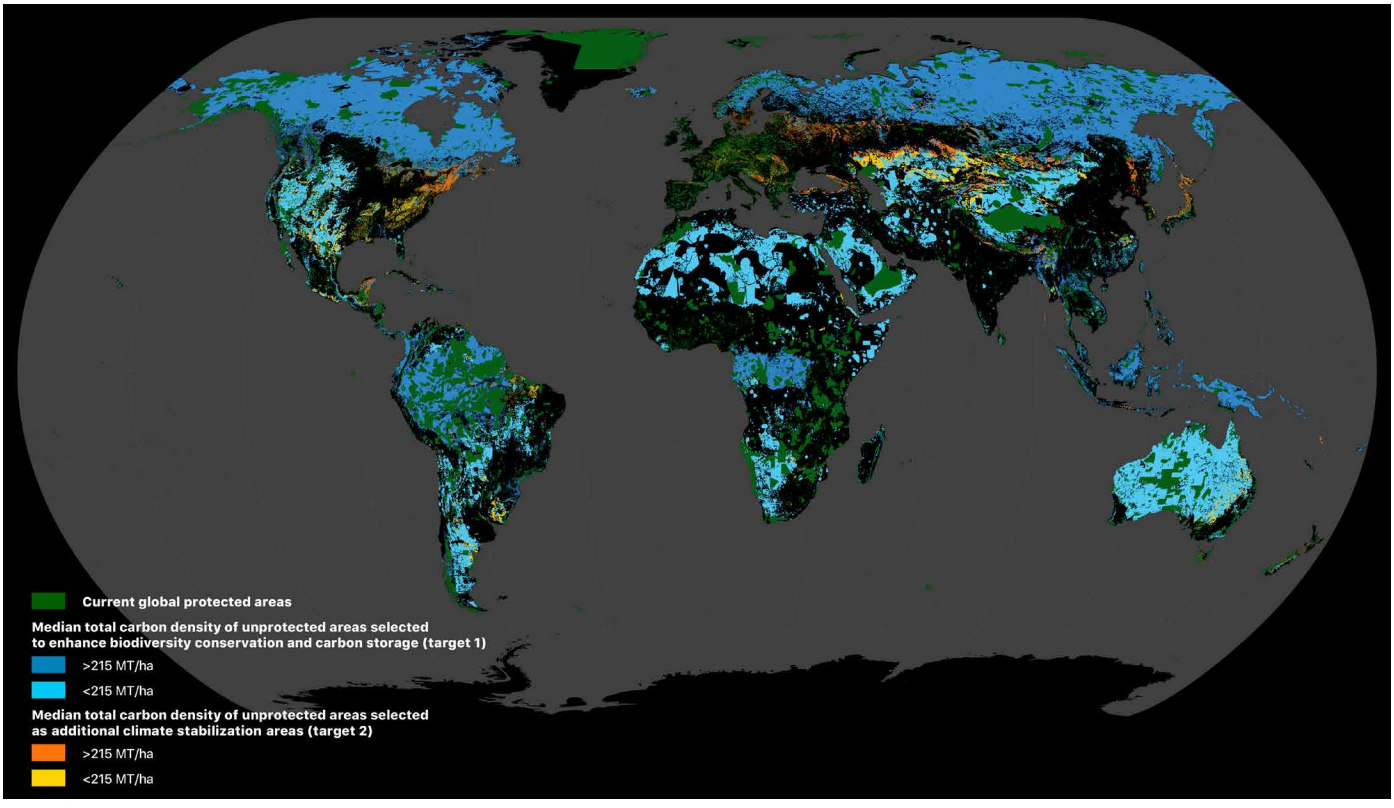

Fig. 2. Interdependence of carbon and biodiversity. Currently unprotected high-carbon areas with median total carbon >215 MT/ha overlap extensively (92.0%) with areas selected under target 1, highlighting the importance of these lands for biodiversity conservation and climate stabilization. Other areas important for biodiversity but of lower carbon value, i.e., <215 MT/ha, are also shown. Additional CSAs, including tier 1 and tier 2 CSAs, are also selected to bridge the gap for adequate carbon storage beyond areas identified in target 1.

nation on Earth toward the collective goal of protecting ecosystems, halting land degradation, and stopping biodiversity loss. Most conservation efforts and land use decisions are local or regional in nature, and implementation of the Global Safety Net will occur from the ground up, by district, state, province, and nation. Saving biological diversity and stabilizing the climate will require increased conservation action, but the tools and designations will vary by place and must be locally appropriate. Countries and indigenous communities will use a variety of designations from International Union for Conservation of Nature (IUCN) category 1 protection levels, to OECMs, to CSAs managed for retaining vegetative cover and preventing emissions.

While our analysis makes a distinction between areas managed for biodiversity and those additional areas managed for climate stabilization, a target could still be reached if land were designated as a CSA and managed for priority species. In the current environment, we could also envision intact areas set aside under a pandemic prevention program. These natural habitats would be managed and protected to avoid conversion and reduce human contact with pathogens that lead to zoonotic diseases in areas of high risk. Protecting wildlife in these pandemic prevention areas from overhunting, restricting access to bat caves and roosts, could also reduce the potential for more catastrophic outbreaks.

Future iterations of the Global Safety Net should incorporate additional biodiversity metrics (including marine and freshwater species) and layers that could help inform food and water security. Current and future energy and transportation infrastructure should also be included. Connectivity analyses should be refined by ecoregion to account for the habitats and species populations requiring connectivity and to account for likely climate impacts. To this end, we have designed this version of the Global Safety Net to be updated by adding new data layers and allowing for dynamic analyses via Google Earth Engine (*39*), so that targets may be adjusted in real time as changes in land use occur. Future iterations can also incorporate higher-resolution ecoregional plans, recent spatial data on arable land, agricultural productivity, yield gaps, energy needs and resources, water balance, and the most recent climate models and various carbon maps. Ultimately, these evolving maps can refine pathways for conserving Earth's land surface to save the diversity and abundance of life, to produce enough food for humanity, and to stay within the bounds of a safe operating space to ensure the well-being of future generations.

For the Global Safety Net to be politically achievable requires broad engagement from civil society, public agencies, communities, and indigenous peoples. Yet, it is also essential to state clearly that the formulation of the Global Safety Net in no way is intended, is not based on, and does not advocate taking current agricultural land out of production, removing indigenous or other people from lands, or implying that 50% of all 846 terrestrial ecoregions be conserved. In particular, with regard to indigenous peoples, the Global Safety Net reaffirms their role as essential guardians of nature.

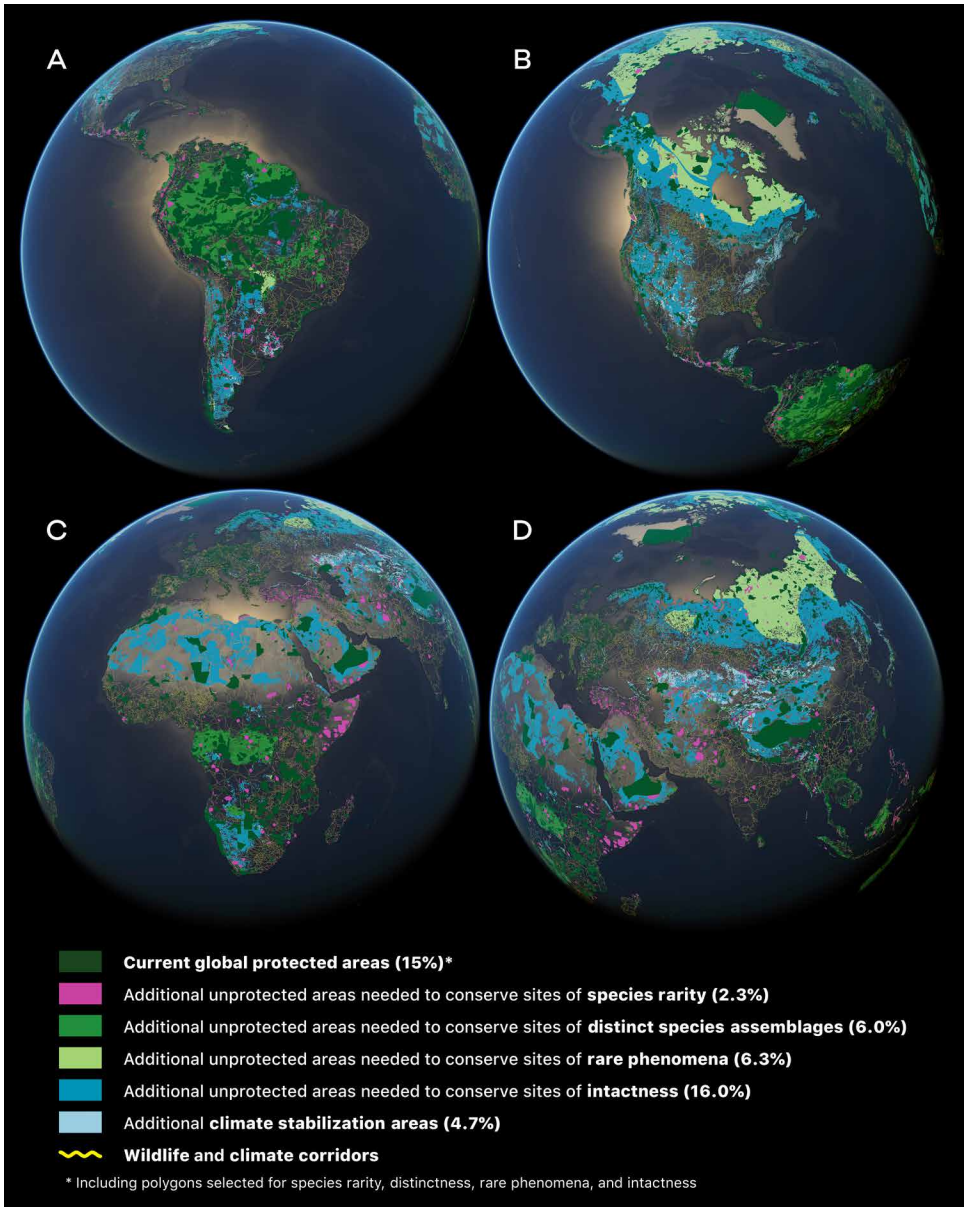

Fig. 3. The Global Safety Net made more visible in a close-up of five biogeographic realms. Shown here are Neotropic (A), Nearctic (B), Afrotropic (C), and Palearctic and Indo-Malayan (D) (adjacent realms partly included). Existing protected areas are expanded to account for additional lands requiring increased conservation attention (target 1), augmented by additional CSAs (target 2), and connected by potential wildlife and climate corridors (target 3). Numbers in parentheses show the percentage of total land area of Earth contributed by each set of layers. To explore the component terrestrial layers of the Global Safety Net, please visit www.globalsafetynet.app. Indigenous lands are not shown but overlap extensively with proposed areas for increased conservation attention (see table S2 for ecoregions depicted in Fig. 3).

The level of planning and foresight that is needed to properly scale nature conservation requires the emergence of a worldview that embraces the notion of stewardship at a planetary scale. Decades after the famous motto "think globally, act locally" was coined, the Global Safety Net offers a possible solution to today's converging socioecological crises, from local to global. Human societies are late in the game to rectify impending climate breakdown, massive biodiversity loss, and, now, prevent pandemics. The Global Safety Net, if erected promptly, offers a way for humanity to catch up and rebound.

MATERIALS AND METHODS

Rationale for data layers and sources

Species rarity (layers 1 to 6)

Many species are naturally rare, that is, they have narrow ranges, occur at low densities, or exhibit both conditions (*16*). Other species may once have been widespread and common, but as a result of human activities such as habitat conversion, overhunting, or invasive species, now have limited ranges or few remaining individuals. Conservation biologists have devoted considerable effort to mapping narrow range endemic and threatened species. Most of these data

layers are generated using optimization approaches to conserve the maximum number of species in the smallest area possible.

Distinct species assemblages (layers 7 to 8)

Almost all conservation priority mapping to date is informed by α-diversity—the number of species present in a given area. Much neglected is β-diversity—the turnover of plant and animal species communities with distance and along elevational or environmental gradients. The turnover effect creates distinct species assemblages, a conservation priority in its own right. High levels of β-diversity are characteristic across tropical moist forest, tropical dry forest, tropical grassland and savanna, tropical montane grasslands, Mediterranean climate shrublands, and some of the tropical xeric biome. Many of the high–β-diversity ecoregions have undergone extensive conversion and are recognized as biodiversity hot spots (*20*).

Rare ecological and evolutionary phenomena (hereafter rare phenomena; layer 9)

This cluster addresses unprotected landscapes containing rare global phenomena. Here, we include areas containing the last intact large mammal assemblages of the terrestrial realm (including species such as large mammalian carnivores that are rare locally but range widely) (*21*). Some of these large polygons also overlap with terrestrial large-mammal migrations of the most wide-ranging large-mammal species, perhaps the most endangered ecological phenomenon on Earth (*40*).

The latter element is not comprehensively mapped on a global scale but could be added to this category. Other rare ecological and evolutionary phenomena, not included in this formulation, are aggregations of breeding species, sites of adaptive radiations across multiple taxa, and migratory stopover sites. Some of the polygons selected in layers 1 to 8 and 10 and 11 encompass these incompletely mapped elements of biodiversity. KBAs, for example, include many migratory stopover sites and breeding aggregations of birds.

Intactness (layers 10 and 11)

Maps of wilderness and intact forest landscapes show that structurally intact habitats are increasingly rare (*23*, *41*). Large intact habitats contain ecological features that cannot be conserved in the small polygons characteristic of ecological elements in the first two clusters. To this end, we included the Last of the Wild in each ecoregion (*22*) and wilderness areas (*23*).

Mapping the elements

The current version of the Global Safety Net is formulated from 11 biodiversity layers (fig. S1, A to K, and table S1). We partitioned two of the above datasets to calculate a median pixel values: IUCN range-size rarity raster (median = 0.006) (*17*) and small-range vertebrates raster (median = 24) (*15*). For both datasets, only pixels greater than or equal to the median values were used. In the case of rare plant species, to be conservative, we excluded pixels containing only one to two rare plant species. The rationale here is that some of these are known from one to a few specimens. All raster data were converted to vector data (polygon) for further analysis.

We overlaid each of these biodiversity data layers with all terrestrial protected areas (*14*) to remove areas already set aside for conservation. To remove double counting, we subtracted any overlapping areas with previous datasets. For example, all AZEs are included as KBAs. We ingested resulting layers into the Google Earth Engine to derive remaining habitat in each layer using percent tree-cover maps (*42*) in forested ecoregions (except boreal forests) and excluded globally significant patterns of human land use and populations ("anthromes") in nonforested ecoregions (*43*) [see (*1*) for detailed methods]. We selected all nonoverlapping unprotected areas within each of layers 1 to 4 and only the remaining habitat for layers 5 and 6 as contributions toward target 1. For layers 1 to 5 within "species rarity," we added a 1-km buffer around all unprotected sites except layer 6, rare plant species, as the size of a "rare plant pixel" was ~10,000 km^2.

To estimate carbon storage potential by biodiversity layer to construct (Fig. 2, Table 1, and table S1), we first overlaid a map of total carbon biomass (*24*)—which includes above ground, below ground, and soil carbon—with terrestrial ecoregion boundaries (*1*) to derive the median carbon density for each ecoregion. To determine CSAs, we selected ecoregions with a median total carbon density >215 MT/ha as candidates for tier 1 CSAs. Ecoregions with a median total carbon density between 50 and 215 MT/ha were designated as tier 2 CSA candidates. Ecoregions with low levels of carbon density (<50 MT of total carbon per hectare) were not selected as potential sites for additional CSAs. We then selected all remaining habitat outside protected areas after removing any overlap with the 11 biodiversity layers to derive the polygons for tier 1 and tier 2 CSAs.

On the basis of the best available literature, we designed wildlife corridors to meet the ecological requirements of the most wide-ranging species that must disperse as part of their life histories and climate corridors that would allow species movement up and down mountainsides, along riparian corridors, or across human-dominated landscapes (*44*). The connectivity analysis was a computationally intensive analysis that included producing a cost-distance matrix, weighing land cover classifications, buffering, and processing. The cost-distance matrix surface was developed as a surface intended to represent varying levels of resistance for wildlife to move along a landscape with regard to vegetation cover, slope, roads, and other land uses. While future iterations should be more specific to ecoregions and local fauna, for this first global scoping phase, we used continents as the unit of analysis and corridors were modeled considering variables that are potentially important for the gene flow of terrestrial species generally. We weighted both variables and classes, depending on the type of data, so that higher weights were given for factors that have higher costs. Land cover data were obtained from the European Spatial Agency with a spatial resolution of 300 m and was reclassified considering the degree of anthropized areas. Urban areas and water bodies were excluded from the modeling. Roads, railways, and mining areas were buffered. The design of the corridor network and the links between core areas was done with the Linkage Mapper Toolkit of the Circuitscape project (www.circuitscape.org). A full description of the methods is available from the authors.

Sources of variation

Here, we identify five potential sources of variation in our results that could be improved in future iterations of the Global Safety Net. We also point to how variants in methods or data sources differ from other, recent efforts to map global biodiversity (*3*, *15*).

1) Total areal extent of the terrestrial realm

The total land surface we used to produce the Global Safety Net is based on Earth's entire terrestrial area excluding Antarctica, which amounts to 134,126,000 km^2. Much of Antarctica includes rock and ice, and the 18 tundra ecoregions on the continent do not contribute

to the key targets of the Global Safety Net. The total land area calculated by this method is closely comparable to that adapted by the World Database on Protected Areas from which they derive the 15.1% terrestrial coverage that is the standard used in other biodiversity analyses in preparation for the Convention on Biological Diversity. As a result, the Global Safety Net does differ from other studies—Allan *et al.* (*3*)—that use a larger total terrestrial area estimate of about 146,000,000 km^2. The 44% of Earth's terrestrial area that Allan *et al.* (*3*) call for increased conservation attention amounts to 64 million km^2. In contrast, the 45.7% of Earth's terrestrial area included under Global Safety Net for currently protected areas and target 1 totals 61.3 million km^2.

2) Potential but limited error of inclusion of nonhabitat from cluster 1 datasets

When applying layers 1 to 4 of cluster 1, we used the original polygons provided by the authors of each dataset. As a result, these four data layers include varying amounts of nonhabitat within each selected polygon. We did not apply habitat suitability modeling to refine these datasets as it would further fragment these critical areas for narrow-range and rare species, which could have detrimental effects for biodiversity conservation, especially where some of these adjacent nonhabitat areas are prime candidate for restoration or reconnecting via wildlife corridors. For those reasons, we used the original polygons, including nonhabitat areas, in our analysis for cluster 1. The inclusion of nonhabitat areas is essentially moot because of its limited spatial extent: Summing the entire area of nonhabitat from layers 1 to 4 adds only 388,089 km^2 (or 0.3% of the total land surface of Earth to the 2.3% selected for cluster 1). We suggest removal of nonhabitat is best performed at the ecoregion scale by local experts and done on a case-by-case basis.

3) Remaining habitats in layers 5 to 11

A goal for the Global Safety Net is to identify near-term opportunities to achieve the global nature conservation target, i.e., areas where additional protection can have the most effective conservation outcome. Thus, we focused on suitable natural habitat remaining without the need for major restoration. We therefore selected only intact or semi-intact habitat remaining outside currently protected areas to derive potential contributions to the Global Safety Net from layers 5 to 11 (clusters 1 to 4) and from additional areas for carbon storage (CSAs).

4) Indigenous lands

We overlaid the Global Safety Net with the most recent global map of lands managed or controlled by indigenous peoples (*26*) to determine the extent to which such lands overlap with the existing network of protected areas. The intent was to illustrate the role such lands could have in enhancing biodiversity protection and carbon storage if this were the intention of peoples managing such areas. Two sources of variation are noted: (i) Many indigenous peoples' lands remain unmapped. Blank areas merely indicate that no publicly available datasets currently indicate the presence of indigenous peoples from those areas; the map, however, should not imply absence of indigenous peoples. (ii) The scale at which indigenous lands are mapped in is based on multiple public datasets varying greatly in spatial resolution (*26*). For example, polygons in the Sahara and in the tundra ecoregions are much larger and more coarse grained than those mapped within the United States and the Brazilian Amazon.

5) Using median carbon density per hectare across the ecoregion as a proxy for carbon value for individual pixels in each ecoregion

Total carbon was mapped as metric tons per hectare for each pixel (pixel size ~0.09 km^2 at the equator) (*24*). We used the zonal statistic tool in ArcMap 10.6.1 to calculate median total carbon value for each of Earth's 846 terrestrial ecoregions (*1*). As a result, the values for median total carbon density per ecoregion include pixels that are classified as protected areas, remaining habitat outside protected areas, and nonhabitat (e.g., cities and agricultural lands). To estimate the total carbon that could be safeguarded via additional protection of lands under targets 1 and 2, we multiplied the carbon density of the ecoregion by the area of remaining habitat for each data layer in that ecoregion that could contribute to the Global Safety Net. However, our approach implies that the total carbon added in certain ecoregions may be overestimated or underestimated. For example, in an ecoregion where the majority of the habitat is protected, the median total carbon density per hectare for the ecoregion could be higher than the carbon density per hectare of the habitat remaining outside protected areas. Alternatively, in an ecoregion containing a large expanse of nonhabitat (urban areas or converted lands for agriculture), the median total carbon density for the ecoregion might be lower than the carbon density of the habitat remaining outside protected areas.

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/6/36/eabb2824/DC1

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A "Global Safety Net" to reverse biodiversity loss and stabilize Earth's climate

E. Dinerstein, A. R. Joshi, C. Vynne, A. T. L. Lee, F. Pharand-Deschênes, M. França, S. Fernando, T. Birch, K. Burkart, G. P. Asner, and D. Olson

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Secretary Rebecca Tepper
MA Executive Office of Energy and Environmental Affairs
100 Cambridge St., 10th Floor
Boston, MA 02114

January 22, 2024

Dear Secretary Tepper,

As a regional land trust serving the most rural county, in the third most densely populated state in the country, whose mission is the conservation of the working landscape, we at Franklin Land Trust and the MA Woodlands Institute would like to offer our feedback on the *Report of the Climate Forestry Committee: Recommendations for Climate-Oriented Forest Management Guidelines.*

We thank the committee for dedicating so much time and effort to considering these issues. We applaud the recommendation of all committee members to put permanent preservation of forested land as a top priority of state land managers and partners in order to reduce land conversion, increase permanent land conservation, and enlarge forest reserves.

We support the committee in recognizing the importance of wildlands and encourage agencies to develop a robust process to identify and formally designate more wildlands within state holdings, as part of larger integrated stewardship plans. We support recommendations to incorporate climate change considerations into BMPs and committing to the implementation of the State Soil Health Action Plan and Resilient Lands Initiative.

We commend the committee for directing the Commonwealth to carefully steward public lands by employing active and passive management strategies to maintain our forest ecosystems and forest cover, to protect existing carbon stocks and sequestration capacity, The Climate-Oriented Forest Management Strategies and Combined Climate-Smart Practices are welcome, science-based guidelines, which along with continual research, monitoring of forest condition and treatment outcomes, and adaptive management by agencies will help us reach our common goals.

We would also offer the following feedback for your consideration on the report:

The laudable goals of protecting 30% of Massachusetts lands by 2030 and 40% by 2050 and reducing the conversion of forest land by 50% by 2030 are noted to require the doubling of the current pace of land protection. This is in alignment with our organization's mission and matches the commitment to the future of the environment held by our members and supporters.

However, in order to attain these goals while balancing the needs of the rural communities in our region requires commitment of substantial funds and technical assistance on the part of the state administration and partners to:

- Commit to increasing funding for land conservation and stewardship by several orders of magnitude
- Promote viability of municipalities through PILOT and environmental funding programs
- Acknowledge and create strong partnerships to increase land equity and reduce barriers to land access
- Support the critical role of Traditional Environmental Knowledge (TEK) and Indigenous and Local Knowledge (ILK) in the cultural integrity of Indigenous peoples, and climate change resilience

The report notes disagreement among members of the committee on matters of the balance of active and passive land stewardship. We offer these points to help steer towards consensus and strong, fact-based decision making:

First, we recommend that the findings of this committee be put in the context of holistic carbon accounting for the Commonwealth including all carbon-emitting industries and sectors. Forested land stewardship and climate change response cannot be looked at in isolation from reduction of atmospheric emissions by energy, construction, transportation, heating, manufacture, and agriculture. The state and its land managers require guidance from a holistic view of the role of the forested resource in an environment of global markets in order to make the critical decisions recommended by the report. This lack of accounting has profound effects on the discussions regarding both management and overall forest ecology, with regard to carbon sequestration and storage.

Under a holistic carbon accounting, the Commonwealth can look at the best management strategies to create the most robust, resilient, and diverse forests under its ownership, from wildland reserves to young forest habitat. A forest that produces carbon neutral products for a state that consumes more forest products than it provides. A thoughtful discussion of management within this accounting could lead to shared goals, outcomes and a myriad of environmental services that are particularly salient to this report.

Second, follow with information gathering about storage of carbon in wood products and replacement of fossil-fuel based products and services. Next steps from this report should be to provide information about end use of forest products, forest resources for local building materials and technology, the use of forest products for paper products for packaging, or use for efficient, clean, thermal energy – all of which offer opportunities for reducing carbon emissions from fossil fuels.

If markets existed for all of these products it would have a profound impact on forest management in Massachusetts. It would allow the forest manager the ability to remove low quality products which would allow for higher quality residual stands and uneven aged management, high quality silvicultural activities and remove the pressure for high grading. More robust markets would allow woodland stewards to see better outcomes and be more able to keep their forests as forest. Efforts by the State to develop and promote these markets, would affect private lands and have an effect on the overall forest carbon accounting.

Massachusetts consumes tremendously more wood products than it produces, and it harvests well below its annual growth. This imbalance shifts the responsibility for providing good stewardship, management goals and products to somewhere else outside of our state. We request the committee and administration consider and provide tools for consumers to weigh these options and make good decisions for products made in or outside of Massachusetts. There are opportunities here for information about where wood products come from to help residents ask whether they are better suited to be resilient to climate change than the temperate forests of Massachusetts, which have evolved with natural and land use disturbance and with guidance from Indigenous land stewards for millennia. The state could support the creation of initiatives and efforts to leverage MA consumers' buying power to require accountability from wood producers. And for products brought in from

elsewhere, find ways for those produced sustainably to be prioritized for purchase over unsustainably harvested materials, and seek to reduce the impact of greenhouse gas emissions through production and distribution.

Third, embrace opportunities for leadership and factor in cascade impacts on private sector and partners into state stewardship decisions. Collaboration with state lands management has powerful impact. As a land trust that manages its portfolio with a number of goals that reflect a broad sweep of outcomes from wildlands to young forest habitat, grasslands, shrublands and productive forest lands, we rely on a number of partners and research institutions to help us achieve those goals. We do so with a desire to manage lands with reference to the surrounding landscape, resiliency and carbon sequestration and storage while producing products for the local economy where possible. Our managed conservation areas provide concrete demonstrations to our members and community members for techniques of management: from hands off wildlands to intense shrubland habitat management. We have helped private and public land stewards with grant opportunities to manage our lands for a more resilient landscape through both state and federal programs. In addition, our subsidiary Massachusetts Woodland Institute administers DCR's Working Forest Initiative which helps private land stewards get forest management stewardship, bird and climate plans.

Public lands are important not only as natural land with a variety of values and benefits, but as models for private land steward activities. Lack of active management on state lands could place the burden for active wildlife habitat management and production of forest products in Massachusetts onto private lands, while simultaneously reducing the ability of the state to model high quality management for those activities. If the state moves to model a broadly passive approach to forest management within its own lands it will put two pressures on private woodlands that will be in tension. One will be the burden of private forests to meet demand which may create more cutting. The other will be a hands-off approach by land stewards who will follow the State's lead. Regardless, this will put more pressure on private lands. Economic pressures and potential confusion on the part of forest land stewards may lead to increased fragmentation and conversion. An outcome we can all recognize as being catastrophic, undermining all our shared goals to maintaining a healthy, resilient forested landscape and increasing our region's ability to store and sequester carbon stocks. Reaching statewide goals for climate change response requires a commitment to increased modeling of ecological forestry and climate informed forestry on state lands, including educational outreach.

Thank you for this opportunity to provide input on the report. We look forward to working together with state agencies, non-profit and private partners to find answers to these questions together, and to find the best solutions available to us all to support the forest, stewards today and in the future, and for all of us to face the challenges of climate change.

Best regards,

Mary Lynn Sabourin
Executive Director
Franklin Land Trust

Emily Boss
Executive Director
MA Woodlands Institute

Comments to EEA concerning Carbon Sequestration and MA Public Lands in the Age of Climate Change

PUBLIC IMPUT:

To the general public this comes down to either manage or don't manage. The default position seems to recommend passive management which eliminates the modern day economy of big heavy logging equipment that requires fast harvesting at the expense of soils and vegetation. But this avoids the problem of declining forest health due to climate change, herbivores, invasive plants, insects, and tree diseases. The CFI inventory program shows mortality increasing faster than growth, on all public lands, which means in the near future mortality will be greater than growth, on these public lands. What then? It seems that only herbivores and invasive plants might be controlled and probably not enough to stem surging mortality.

EARLY SUCCESSIONAL VEGETATION:

I agree with the report, it isn't necessary, since it happens due to the forces of climate change.

SALVAGE:

This is a difficult subject and one that doesn't fit an either yes or no. It should be done on a case by case basis. What is left is more important then what is taken, something like sculpture. But the taking must be carefully done with small, light equipment (<100 HP) and hand felling. with logging trails on less then 10% of the salvage area. Any proceeds would be spent on restoration planting that may require fencing.

OLDER FOREST:

This phrase needs a definition. Much of our intact MASS forest stands are in 2 age classes originating from the massive harvesting of the beginning of the last century and from the 38 hurricane. Is this old? On my own woodlot I have hemlocks in the 200-300 year old age class. Lots of defects and insects are slowly eliminating them. If anyone is familiar with the UNH forest in Durham and watched it over the past few decades, this colonial era forest has sucummed to rot and few are left standing. Trees decline in health for many reasons and the ones that avoid pathogens are usually on the best sites, rich mesic sites where carbon sequestration reaches the highest levels.

RESLIENCE:

I think the only way to have reslience in the forest, especially in the era of climate change, is to carefully tend the forest which provides more resources to the best performing trees. This means more light and moisture by removing low performing trees and also aids the forces of plant succession.

EXEMPLARY FOREST PRACTICES:

This phrase is often used by public land agencies, but without a definition. It is assumed that agencies that are not pressed for any significant crevenue from the sale of forest products, naturally do a high level of stewardship. Viewing the forest practices on Public Land in the area I live does not meet the meaning of exemplary. Hence we need a thourgh definition of this phrase.

FOREST SOILS:

Soils are the foundation of the forest. We are learning more and more of how they allow the connections of trees and plants with fungi, bacteria and viruses for the benefit of all. But they are sensitive and heavy logging equipment that compacts, ruts and mixes forest soils destroys these connections and most important slows or restricts the movement of water through the soil and forces it to run over the ground.

In terms of the climate emergency, we must be particularly clear eyed now about the risks and benefits of our forest policies and act with urgent intent. There are increasingly smaller windows within which we can take restorative action. The role of forested land is paramount. I agree with the IPCC report's conclusion that: "protection of the existing natural forest ecosystems is the highest priority for reducing greenhouse gas emissions."

There are many ways in which I agree with the Committee of twelve that produced the Forests as Climate Solutions report, in particular, "maintaining forest cover is essential" and their "strong support to reduce land conversion, increase permanent land conservation and enlarge forest reserves."
I'm in agreement with the report's strong statement, "Unsurprisingly, disturbing the forests of MA as little as possible and allowing forests to grow and age through passive management is generally the best approach for maximizing carbon, ecological integrity and soil health." The next sentence in the Executive Summary, "However, Massachusetts must manage forests for multiple purposes and benefits simultaneously." That last statement, can be true but requires multiple qualifiers. If you are talking about ecosystem benefits, in the ways that MA Audubon does you are including: carbon storage, flood control, water supply, water filtration and infiltration, biodiversity, cooling and shade, scenic beauty, recreation, and generally enhancing "the quality of life and community character", as the purposes and benefits of forests, then I agree. We can have all this with forests allowed to reach maturity and for the most part being passively managed. It is when the "multiple purposes and benefits" spoken of are inclusive of logging that I can no longer simply agree. Now it depends on where the logging occurs, how exactly is it done, how often, how much of it is necessary, how much is allowed, who has ownership, who has supervisory authority?

If logging is excluded from the discussion the charge of the Committee would have been to answer the question, How can forests help solve the climate crisis and continue to provide maximum ecosystem benefits? And further, How can we help forests to do that?

When logging is included in the discussion the question alters greatly, and feels more like, How do we get everything we need and have historically gotten out of our forests, while we additionally use them to help solve our climate crisis?

One of the most important things when trying to solve a problem is to ask the right question.

I do not consider logging to be any type of climate solution. It is an extractive industry with climate consequences. For the climate, for the planet and the world's ecology, trees are always most valuable in a healthy living state; left to grow to maturity, becoming areas of old growth forest complete with its enhanced carbon storage, complex biodiversity, greater moisture retention, healthier soil, lush with organisms, microorganisms, fungi and able to also store larger volumes of soil carbon with the immense cooling effect from the resultant shade from the greenery and the transpiration that occurs in the small water cycle produced within a forest.

However, we do use, and will continue to use wood and wood products into the foreseeable future. We need to look at that use and do it wisely, conservatively and with awareness. We need to consider and recognize the losses, every loss we are incurring from using this resource in any way that is anything other than promoting forest health and longevity. This needs to be done in a transparent fashion so the state agencies know their mandates and so that their policies are clear. The public needs to be aware of the trade-offs involved in the decision making. Transparency and honesty allows the public to participate effectively from a base of knowledge and hopefully encourages an alteration of their consumption to better reflect sustainability goals and practices.

In the totality of forested lands in MA, the state owned lands represent a limited proportion. In light of this and that these are the forests that the state has the most control over, I think we could decide to keep them primarily free from logging, rapidly increasing the proportion of forever reserves suggested in the report, maintaining healthy biodiversity, providing people with the spiritual and health benefits of protected outdoor spaces, maintaining healthy watersheds as well as using some state owned property to conduct additional research into the areas on resilience where Committee members couldn't seem to agree on the best actions to take or resist taking to most effectively support greater resilience.

I want to also be clear, I am not in favor of getting all the wood stuff we want from somewhere else and therefore just putting the damage from our use of wood in another's backyard. As with all limited resources we need to learn to use less, use resources more efficiently and with more reverence, recycle what can be and create a philosophy of a circular economy where materials are not wasted in all the ways possible but their usefulness extended and preserved over the longest period of time.

So, my hope is that on currently privately-owned lands, we incentivize more areas of passive management and areas that become permanent forest reserves as well as areas of active forest management, where there is logging but it is also incentivized to be as sustainably done as possible, addressing some of our forest product needs locally. Wherever the wood comes from attention should be paid so that the climate damage associated with our available wood products is minimized in every way possible.

I had hoped to learn more from this report. Specifically, I have been trying myself to develop more knowledge so that I could develop an educated opinion about where and how humans should intervene in forest ecology or in fact if they ever should. Man has a poor track record for improving the natural world with our historical practices and interventions. Nature, however, has an innate resilience and what I've witnessed is that given any chance, nature will heal and repair enormous damage. Given the stressors we have thrown at forests and our planet's ecology should we simply stop the stressors in every way possible or do we have any wisdom, to add to nature's wisdom, which we can provide to enhance our forests ability to regenerate and combat pests, diseases and other unfavorable conditions such as invasive plants and the tremendous loss of biodiversity. Additionally, should we be managing forests to help them transition to future conditions. The Committee did not seem to agree on much in this area that

fell under the heading of resilience. I am still unable to fully commit to a firm opinion here, although I do lean more in the direction of placing my faith in nature's wisdom. What I can say firmly is that we need multiple sizable areas where forests are just allowed to manage themselves, where nature takes its own course amid our changing climate and the alterations and added stressors that will exist. We need to let those areas succeed or fail while we carefully use science based observation to record the results. Because current and coming conditions are unprecedented we need to learn, as a baseline, how effectively will nature adapt when left to its own devices. We need to know these results at least as much as what will be the successful or detrimental results from interventions that humans will try in our efforts to help forests.

Thank you for your attention to my comments. I'm sorry they are a few hours late in getting to you. I appreciate the Governor and her administration for initiating this important effort and thank the Committee members for their time and input. Please take great care in formulating the questions we need to answer. The climate crisis and its impacts are enormously challenging, costly and extremely inconvenient. As Al Gore said some time ago, they are An Inconvenient Truth.

My best to you in your efforts,
Marcia F Hart RN

Shutesbury, MA
January 12, 2024

Dear EEA Staff;

As outlined in the CECP 2050, successfully addressing the climate crisis is a monumental, complex task that requires balancing a wide variety of technical, social, environmental, economic, and financial considerations. Because the Climate Forestry Committee is composed solely of foresters and forest ecologists, its perspective regarding wider energy and land-use realities is perhaps limited. Therefore, the committee recommendations regarding issues outside of forest management should not be given undue weight by policy makers or the public. With that in mind, please consider the following comments:

The report recommends minimizing forest conversion to other land uses (pp. 48, 67), which is generally sound advice when the subsequent land use only contributes to global warming (eg. residential, commercial, roads, agriculture, etc.). However, forest conversion for solar energy is fundamentally different. Multiple studies confirm that limited forest clearing for solar projects can result in a greater net climate benefit than the forested land itself provides. Specifically, if the electricity from a solar facility that is built on cleared forest replaces the electricity from a fossil fuel generator, the carbon offset of the solar facility significantly exceeds the carbon sequestered by the forest itself.[1] For example, a researcher at the Harvard Forest created a "carbon calculator" specific to Massachusetts that models this relationship.[2] Using this calculator under the default (mid-range) assumptions, solar panels installed on 1 acre of Massachusetts forest in the year 2025 will offset a net total of 922.6 metric tons (MT) of fossil fuel CO_2 by 2050, an average of 37 MT per year. The Commonwealth's "Land Sector Report" from its 2050 Decarbonization Roadmap Study, indicates that 1 acre of mature forest sequesters about 2.3 MT of CO_2 per year.[3] Therefore, by replacing fossil fuel generation, the Harvard Forest model estimates a solar project will provide about a sixteen-fold net benefit in mitigating atmospheric CO_2 levels than the forest itself would provide. Given the information above, I suggest that solar energy projects be differentiated from other more traditional causes of forest conversion.

The report also tends to overemphasize the importance of forests as a means of mitigating our past and ongoing CO_2 emissions. In short, the sheer mass of carbon we release each year far exceeds the sequestration capacity of our forests, under even the most optimistic scenarios.[4] Currently Massachusetts' 3-million acres of forested land (more than 60 percent of our land cover) sequesters only about 9 percent of our annual CO_2 emissions.[5] In the implausible scenario that we somehow increase our forest cover to 4.6-million acres, approximating pre-European

[1] Eisenson 2022; Hanig 2019; Lee 2023a; Synapse Energy 2021; Turney and Fthenakis 2011.
[2] Lee 2023b.
[3] Based on cited 5.6 MT CO_2/ha; Thompson *et al*. 2020.
[4] Lu *et al*. 2013; Smith *et al*. 2015; Steffen *et al*. 2016; Walker *et al*. 2022; Zickfeld *et al*. 2021.
[5] Based on sequestration data from Thompson *et al*. 2020 and Mass Clean Energy and Climate Metrics 2020 data: 63.9 $MMTCO_{2eq}$ in-state emissions and 5.88 $MMTCO_{2eq}$ imported electricity emissions (https://www.mass.gov/info-details/massachusetts-clean-energy-and-climate-metrics#nwl_section; accessed December 29, 2023).

settlement land cover, it would still mitigate just a fraction of our current emissions. Also, while the carbon being released from fossil fuels has been stored in geological formations for many millions of years, there is significant uncertainty surrounding the permanence of forests as a sink for atmospheric carbon.[6] At any time, carbon sequestered in forests can be released back to the atmosphere because of natural causes (eg. storms, fires, diseases) or future changes in land-use policies. Therefore, we cannot rely on forest sequestration as a primary means of mitigating climate change.

I present these comments only to stress the critical importance of reducing fossil fuel CO_2 emissions and to provide context for the tradeoffs between forest clearing for solar, which offsets fossil fuel emissions, and the carbon sequestration potential of an equal area of forest. I do not advocate that forest sequestration is unimportant in the long term or that forests should not be protected from indiscriminate loss. But at this time, our highest priority must be the immediate and drastic reduction in CO_2 emissions to limit global warming and negate the need for even more sequestration capacity in the future. Thank you for considering my comments.

Sincerely,

/s/ Keith Hastie

[6] Groom and Venmans 2023; Mackey *et a*l. 2013.

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Mass Audubon

January 24, 2024

Stephanie Cooper, Undersecretary for the Environment
Executive Office of Energy and Environmental Affairs (EEA)
100 Cambridge Street, Suite 1020
Boston, MA 02114

VIA Email: guidelines@mass.gov

Re: **Comments on Forests as Climate Solutions Report**

Dear Undersecretary Cooper and EEA staff:

Mass Audubon applauds the Commonwealth for undertaking the Forests as Climate Solutions initiative and offers the following comments on the *Report of the Climate Forestry Committee: Recommendations for Climate-oriented Forest Management Guidelines*. Protecting and stewarding Massachusetts' forests is essential to addressing the three crises of biodiversity loss, climate change, and inequitable access to a healthy environment, and to securing for the future the many values associated with Massachusetts' forests. The report addresses the numerous, complex, and interconnected issues and challenges requiring attention and action to achieve all the Commonwealth's goals for forests.

Summary Comments – Support for Key Recommendations

The recommendations are generally appropriate and well thought out, including recognition of areas where the Committee did not reach consensus. Some of those issues are best addressed through more detailed planning and implementation processes, and decisions will likely vary from site to site and across different land ownerships. We would like to highlight the following key points:

Increase Land Conservation: At the broad statewide scale, Keeping Forests in Forest is the most important priority, since once land is developed its forest functions are nearly always lost forever. The commitment of $50 million per year to land conservation by the Healey Administration is an important first step in the right direction. Reaching land protection targets of 30% of Massachusetts by 2030 and 40% by 2050 will require new sources of funding at a level commensurate with the level of ambition reflected in these goals. Funding needed to deliver on forests' role in climate mitigation and biodiversity protection is in the hundreds of millions over the next decades, as states like New York have recognized with the passage of a $4B bond intended to scale their investments in nature as a climate solution. Finally, we encourage the state to increase the 2050 goal to 50%, consistent with national and international goals.

Increase Reserves and Conduct Active Management: Both active and passive management approaches are important tools. The appropriate application depends on several factors including: context and landowner management goals; site history and current condition; climate and other stressors; and land ownership and connections with adjoining lands. We agree that forests need to be managed for carbon sequestration and storage as well as many other functions and benefits. Increasing reserves and late

successional forests should be pursued, along with management of other areas where necessary for habitat, climate resilience, and public safety (e.g. trails, fire hazards).

Transparency and Collaboration: Transparency in planning and implementation of management on public lands is important and must be carried out within those agencies' statutory missions and mandates. State agencies need to improve transparency and communication about why management measures have been selected, and the science behind those decisions, through processes that engage the public and provide meaningful opportunities for review and input. In addition to transparency, extensive collaborations will be necessary to achieve the state's goals for forests. Increasing land in reserves requires cooperation across many landowners, both public and private, including municipalities and land trusts. We support commitments by the state to work with adjoining landowners on assembling interconnected, protected networks of land including expanded reserves. Cooperation should also be applied wherever feasible on active management plans to optimize results and avoid working at cross purposes on adjoining lands.

Additional Detailed Comments

These comments are organized into Areas of Agreement and State Considerations for the agencies' response to and implementation of the recommendations, as requested in the Comment Form.

Areas of Agreement/Support:

As noted above, Mass Audubon strongly supports:

- increased funding for land conservation,
- improved planning and transparency for both active management and expanded reserves, and
- enhanced transparency and cooperation by the agencies with the public and other landowners including municipalities and land trusts.

Reserves: We support the proposed goal that 10% of forests in all ownerships should be managed as reserves. We also support a new mechanism for official recognition and permanence of reserves (above and beyond permanent protection from development), potentially including lands in municipal or private conservation ownership with the consent of the landowner. The exact details of this would need to be developed with public input.

Climate-Smart Forestry: The report recommends continued and expanded application of climate-smart forestry practices for state, municipal, and privately-owned lands. Mass Audubon is a partner with the state in the development of the Climate Forestry Program. It is important to recognize that climate-smart forestry includes increased protection of forestlands from development, as well as incentives for landowners to keep their land in forest and to manage it for carbon, biodiversity, and other values. Reserves are also one of the climate-smart forestry practices. For landowners that do choose to actively manage their properties, these guidelines help improve stewardship and reduce impacts from stressors including climate change, invasive species, and excessive deer browse. Urban tree planting is also a climate-smart forestry practice.

Important details that need to be addressed in implementation are discussed below.

State Considerations for Response and Implementation:

Forest Management for Habitat: The report recommends that with implementation of E.O. 618, *Biodiversity Conservation in Massachusetts*, less emphasis be placed on early successional habitat and more on late successional. While we agree that the agencies should be more transparent in how and where they are deciding to conduct active or passive management, it is also important to recognize that the climate and biodiversity crises are not separate but rather are intertwined and need to be addressed together. This perceived conflict would best be resolved by transparent, science-based planning for the overall amounts and the appropriate locations to be managed as reserves or for late successional habitat and for early successional habitat. The overall goals and objectives for habitats should be reexamined periodically through the State Wildlife Action Plan. We agree that the selection of locations for early successional habitat management needs to be made carefully and transparently.

Public Communication and Transparency: All relevant state agencies should have open and transparent processes for engaging the public in planning for management of public lands. This should include overall goals and objectives based in the best available science, and clarity in how and where passive and active management will be employed. The DCR Landscape Designation process has been helpful in providing transparency in a statewide plan for lands to be managed within the agency's multiple use mission. The DCR Division of Water Supply Protection also has a public process for periodic updates to their land management plans. There is no public planning process for MassWildlife lands, nor maps designating which properties are dedicated to active habitat management vs. more passive approaches. It would be helpful to establish a public process for those lands, within the agency's mission.

Best Practices in Collaborative Management: Achieving landscape-level habitat goals requires ongoing coordination beyond the initial protection from development. Some of the public concerns and conflicts around the state's decisions about specific active management projects could be resolved or avoided through increased transparency and cooperation with adjoining conservation landowners and the public as described above. Collaborative planning during land acquisition would also be helpful.

One example we are aware of where there was strong collaboration on land protection but not in advance planning for management illustrates this point. In this example, local municipalities, land trusts, and private landowners worked for decades to protect an interconnected corridor of land in multiple conservation ownerships. There are, however, no cooperative plans or agreements for how those lands were to be managed. Now, several decades after these lands were protected, some lands in state ownership are proposed to be transformed from mature forest to more open habitats, on parcels adjoining and intertwined with municipal parcels owned by several different towns. Members of the local public familiar with these lands had the impression the entire area would be forever wild. There was no process for the state agency to engage with the municipalities in planning for management of these lands, where habitats, trails, and water resources cross the property boundaries in multiple locations. These types of conflicts could be avoided by having the state more clearly indicate its intentions when working cooperatively with a municipality or land trust to protect interconnected parcels of land. For existing state lands, an open and public process for designating which areas will be passively vs. actively managed can help prevent future conflicts. Conversely, municipalities and land trusts should also be encouraged to coordinate with the state when planning for management of parcels abutting state lands.

Management of Energy Utility Corridors: For the overall early successional targets, the report mentions utility corridors as contributing to the overall acreage of open and scrubby habitat. There needs to be recognition that a narrow linear corridor does not meet the habitat needs of some species that require

large blocks of open land away from the forest/open edge. Nonetheless, it would be beneficial to further optimize the management of these habitats. For example, as utilities seek to widen the cleared area along transmission lines for reliability and/or to increase transmission capacity, commitments should be made to management practices that optimize habitat to the extent feasible. Trees and shrubs should not be cut and brush hogging or mowing should not take place during the bird nesting season, for example. That is not always the current practice.

Managing for Multiple Interests: DCR has a multi-use mission, including the production of wood products as well as conservation of natural and cultural resources, water resources protection, and recreation. Recognizing that the amount of wood harvested in Massachusetts is a tiny fraction of that consumed, the amount of wood harvested is a fraction of growth, wood from elsewhere has a higher ecological and carbon cost than local wood, and wood can in some cases substitute for more carbon-intensive materials, producing local wood is not in conflict with climate goals. One goal of climate-smart forestry is to ensure that when harvests occur, they leave a forest that is at least as resilient as before.

Funding for Inventories, Monitoring, Planning, and Management of Stressors: The state agencies, particularly the DCR Division of State Parks and Recreation, do not have adequate staff or funding resources to perform ecological inventories and monitoring, or to address key stressors including invasive species and recreational impacts (e.g., trail erosion, unauthorized trails cutting through sensitive habitats). Municipalities also face similar capacity constraints. The state should address these funding and capacity needs for implementation, including the capacity needed to undertake planning and public input processes as described above.

In conclusion, Mass Audubon is grateful to the Healey-Driscoll Administration for undertaking this process and to the Committee for their thoughtful report, including identification of areas where the experts did not reach consensus.

Thank you for the opportunity to comment.

Regards,

Michelle Manion
Vice President for Policy and Advocacy

Plymouth County League of Sportsmen
Paul Johnson, President
3 Laurie Lane, Carver, MA 02330-1398

January 17, 2024

Secretary Rebecca Tepper
Executive Office of Energy and Environmental Affairs
100 Cambridge St., 10th Floor
Boston, MA 02114

Dear Secretary Tepper,

The Plymouth County League of Sportsmen represents 18,000 Sportsmen and women of Plymouth County. We participated in the Input Session on the Climate-Oriented Forest Management Guidelines prior to the drafting of this proposal.

Our input included the following statements characterizing the challenge of resource management.

"The challenge faced in resource management today is to avoid single issue constituencies which seek to monopolize political discussion. We should be managing our forests for forest health, not carbon sequestration. Forests which are healthy and balanced will support a broad range of healthy wildlife populations and support sustainable production of wood products. Carbon sequestration will be a natural end result of proper management."

"Humans should provide consistent, non-politically driven decisions regarding management of forests and the species that live within it. Decisions that advance reasonable objectives pertaining to clean air, good habitat and wise use of wood products will result in widespread support across the political spectrum."

"Our role in maintaining the condition of forest reserves should be determined by the actual condition of the resource and not driven by political agendas. Forest reserves should support management of species in balance with the habitat."

"Humans need to react to actual conditions not politically motivated expectations. We need to formulate plans that address actual forest vulnerabilities based on science and which utilize a broad range of management options including commercial forestry and other practices that create and manage forests. These plans should produce a mix of healthy forests including old growth, mature and transitional habitats."

We have reviewed the report of the Climate Forestry Committee: Recommendations for Climate-Oriented Forest Management Guidelines. It is clear the committee was not interested in producing a non-political set of recommendations. This report hyper focuses on carbon sequestration, equity, environmental justice and should concentrate on managing forests.

Plymouth County League of Sportsmen
Paul Johnson, President
3 Laurie Lane, Carver, MA 02330-1398

Our members question singling the Division of Fisheries and Wildlife land management policies for change from active to passive management. We trust the Divisions professional managers based on the results they have achieved. We are concerned that many of the recommendations included in this report will increase the cost of management without delivering measurably improved results.

We cannot support this report as written as it is too political and written with a clear bias. Forest management needs to have a broad consensus to be effective.

Sincerely,

Paul Johnson

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From: Dale LaBonte
To: Guidelines (EEA)
Subject: Further comments on the Climate Forestry Committee report
Date: Wednesday, January 24, 2024 9:29:25 PM

In addition to my comments submitted through the form provided, I would like to concur with the statement from the Trees as a Public Good Network:

> [C]limate considerations should be the main criterion for all forest and tree management decisions on public lands.
>
> I agree with the following points of the CFC Report. (1) We should follow the climate-based science that all MA public forests should be minimally disturbed, passively managed, and PERMANENTLY PROTECTED FROM LOGGING so they are allowed to grow and age to maximize carbon sequestration, ecological integrity, soil health, and climate mitigation. (2) The state should buy more land for permanently protected (no-logging) reserves with a goal of reaching 30% of all MA forests in permanent reserves by 2030 and 50% by 2050. (3) The state should provide incentives for private landowners to permanently preserve forests and urban trees. (4) We should follow the climate-based science that we should NOT log in watersheds/reservoirs as it can endanger the public water supply. (5) The state should establish small forested lands in exurban and urban settings as permanently protected reserves.
>
> I disagree with the following points of the CFC Report: (1) MA public forests should NOT serve any economic goals, for example for the wood industry or the land-trust companies. The majority of MA forests are privately owned; these privately owned forests can serve economic goals. (2) The state should NOT log in public forests, especially not in reservoir areas and watersheds. (3) The state should NOT log for early successional habitat and its associated species. We need to allow our mature forests to reach old-growth stages, where the climate benefits are much greater. (4) Incentives for private landowners to permanently preserve forests and trees should NOT replace permanent protection of all public forests.
>
> I urge the state to prioritize the following considerations in implementing the CFC Report: (1) Permanently stop logging on public lands; all projects should be immediately reevaluated for climate (not economic) considerations. (2) Planting trees in urban areas is not sufficient; we need to *preserve* existing urban tree canopy, including making small permanently protected reserves, such as the NEMT Forest (13 acres) and the 4 acres of woods on Morton St. in Dorchester Boston. (3) The state should require *separate* measurement and reporting of greenhouse gas

emissions from and carbon sequestration by agricultural lands, managed forests, and protected forests (no longer aggregating them as Natural and Working Lands).

Dale LaBonte (she/her)
32 Crabapple LN
Northampton MA 01060
413-313-5771

Evaluating nature-based solutions for climate mitigation and conservation requires comprehensive carbon accounting

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Evaluating nature-based solutions for climate mitigation and conservation requires comprehensive carbon accounting

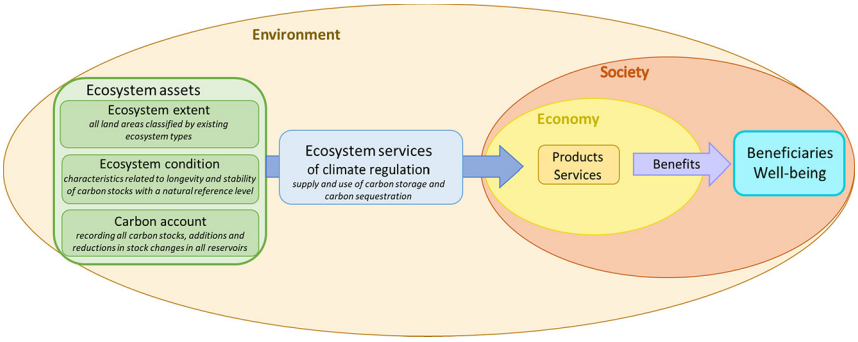
Heather Keith [a,*], Michael Vardon [b], Carl Obst [c], Virginia Young [d], Richard A. Houghton [e], Brendan Mackey [a]

[a] Griffith Climate Change Response Program, Griffith University, Queensland 4222, Australia
[b] Fenner School of Environment and Society, Australian National University, ACT 0200, Australia
[c] Institute for Development of Environmental-Economic Accounting, Melbourne, Australia
[d] The Australian Rainforest Conservation Society, Springbrook, Queensland, Australia
[e] Woodwell Climate Research Centre, Falmouth, MA 02540, USA

HIGHLIGHTS

- New approach for holistic and comprehensive accounting for carbon stocks and flows
- Transparent information in accounts applied to evaluating nature-based solutions
- Ecosystem service of climate regulation includes carbon storage and sequestration.
- Prioritise protection of large, stable, resilient carbon stocks in natural forests
- System of Environmental-Economic Accounting data informs climate change mitigation.

GRAPHICAL ABSTRACT



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ABSTRACT

Nature-based solutions (NbS) can address climate change, biodiversity loss, human well-being and their interactions in an integrated way. A major barrier to achieving this is the lack of comprehensiveness in current carbon accounting which has focused on flows rather than stocks of carbon and led to perverse outcomes. We propose a new comprehensive approach to carbon accounting based on the whole carbon cycle, covering both stocks and flows, and linking changes due to human activities with responses in the biosphere and atmosphere. We identify enhancements to accounting, namely; inclusion of all carbon reservoirs, changes in their condition and stability, disaggregated flows, and coverage of all land areas. This comprehensive approach recognises that both carbon stocks (as storage) and carbon flows (as sequestration) contribute to the ecosystem service of global climate regulation. In contrast, current ecosystem services measurement and accounting commonly use only carbon sequestration measured as net flows, while greenhouse gas inventories use flows from sources to sinks. This flow-based accounting has incentivised planting and maintaining young forests with high carbon uptake rates, resulting, perversely, in failing to reveal the greater mitigation benefit from protecting larger, more stable and resilient carbon stocks in natural forests. We demonstrate the benefits of carbon storage and sequestration for climate mitigation, in theory as ecosystem services within an ecosystem accounting framework, and in practice using field data that reveals differences in results between accounting for stocks or flows. Our proposed holistic and comprehensive carbon accounting makes transparent the benefits, trade-offs and

* Corresponding author.
E-mail address: h.keith@griffith.edu.au (H. Keith).

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shortcomings of NbS actions for climate mitigation and sustainability outcomes. Adopting this approach is imperative for revision of ecosystem accounting systems under the System of Environmental-Economic Accounting and contributing to evidence-based decision-making for international conventions on climate (UNFCCC), biodiversity (CBD) and sustainability (SDGs).

1. Introduction

The Paris Agreement long-term temperature goal cannot be achieved without managing land-use impacts on the carbon cycle (IPCC, 2019a). Provision is made within the Agreement that land-use change should maintain ecosystem integrity and involve integrated actions to prevent climate change and biodiversity loss, as stated in the UNFCCC CoP25 decision 1.CP/25 that "*underlined the essential contribution of nature to addressing climate change and its impacts and the need to address biodiversity loss and climate change in an integrated manner*" (UNFCCC, 2019a). Emission reduction through land-use represents significant components of Nationally Determined Contributions (NDCs) (Seddon et al., 2019a). However, the effectiveness of prioritisation and operationalisation of mitigation actions has been controversial. Much of the controversy about policies and uncertainty in data ensue from the accounting system for carbon stocks and flows and activities that currently includes only anthropogenic changes and does not account for the longevity of carbon stocks. Our proposed comprehensive carbon accounting system would overcome the potential for perverse outcomes from mitigation activities that have been the consequence of the extant accounting rules.

Nature-based solutions (NbS) could play a critical role in changing land management to address both the causes and consequences of climate change and provide an opportunity for increased ambition (Griscom et al., 2017; Seddon et al., 2020), particularly those related to forest ecosystems (Mackey et al., 2020). NbS is being promoted as a strategy for addressing the climate change problem (UN, 2019), but the concept of NbS arose in the broader context of the biodiversity extinction crisis and the need to better protect, restore and sustainably manage ecosystems for the multiple ecosystem services they provide for people (Nesshöver et al., 2017; Cohen-Shacham et al., 2019a, 2019b). However, in practice NbS have come to encompass a range of actions that vary in the quality and quantity of the ecosystem services they generate, including some actions that can result in the loss of biodiversity and ecosystem integrity, and that can be far from optimal in terms of their climate mitigation outcomes (Seddon et al., 2019a, 2019b).

A major barrier to the implementation of optimal NbS is the lack of information about the mitigation benefits arising from alternative actions in a form that enables their effectiveness to be assessed and trade-offs among land management actions to be evaluated. Mitigation benefits represent the ecosystem service of climate regulation, which includes both storage and sequestration of carbon. However, current policy considers optimum forest management as a trade-off between maximising carbon stocks or sequestration rates (IPCC, 2019a), whereas both are relevant to achieve mitigation benefits. Accounting for carbon in the land sector to evaluate NbS requires additional considerations compared with other sectors of the carbon cycle, namely including all stocks and gross flows. Carbon storage in the land sector is dependent on the functional role of biodiversity in providing ecosystems with their stability, resilience and adaptive capacity (Mackey et al., 2020). Hence, accounting for carbon stocks and flows as the ecosystem service of climate regulation must be integrated with accounting for biodiversity in its multiple roles as ecosystem services, including regulation of ecosystem processes, as a final ecosystem service and as goods subject to valuation (Mace et al., 2012).

Policy decisions about management of ecosystems and optimum mitigation actions can only be as good as the information that supports these decisions. Despite advances in many disciplines, such as environmental economics that aims to account for externalities, and scientific data that provides physical evidence, those advances have resulted in little improvement in decision-making or environmental outcomes. Inter-disciplinary approaches to developing information systems are needed to provide a way forward to move science into societal actions and operationalise policies. In developing such a system, the way characteristics of ecosystems are defined, measured and reported have major implications for how ecosystems are perceived, valued and managed. A more holistic and comprehensive approach to carbon accounting is needed if the potential of NbS actions is to be realised and the most effective options prioritised. Accounting needs to include stocks as well as flows, identify ecosystem condition, track changes over time, attribute impacts of ecosystem loss and degradation, and demonstrate the interdependence between ecosystems and human well-being. In the absence of this form of holistic information, investments and government mitigation priorities are not necessarily directed to the most cost effective and optimum NbS actions. Seminal papers over the last decade have argued the need for incorporating accounting for natural capital and ecosystem services into policy and management for sustainable development but present key challenges being mainstreaming NbS in policy databases (Kumar et al., 2020), translating the science into measurable evidence-based targets and policy decisions (Guerry et al., 2015; Seddon et al., 2020) and demonstrating empirically societal values of NbS and their dynamic nature (Calliari et al., 2019).

Our objective is to enhance the concepts, principles and methods underlying accounting for carbon stocks and flows within an environmental-economic accounting framework. This requires inter-disciplinary input into developing more holistic and comprehensive information systems that are needed to support prioritisation of NbS actions. The paper is structured to set the context for carbon accounting for NbS by revealing limitations of current systems and their impact on outcomes of NbS, describing the role of carbon stocks and flows for mitigation, and then explaining the need for enhancing the carbon accounting system to support international polices that are implementing NbS. Our solution is the proposal for enhanced carbon accounting based on the framework for environmental-economic accounting that allows integration with other ecosystem services. We define the essential elements of the accounts and explain the theoretical basis for defining carbon storage and sequestration as ecosystem services. We demonstrate the accounting system using data from a case study to develop a carbon stock and flow account including the condition of reservoirs, and an ecosystem supply and use table. Application of this accounting system is illustrated to prioritise NbS in terms of forest management scenarios and the influence that the accounting rules have on mitigation outcomes. Articulating the distinct benefits of storage and sequestration as ecosystem services for climate regulation reveals a wider range of ecosystem management options for contributing to mitigation actions. Our proposed holistic and comprehensive approach to carbon accounting provides the kind of information needed to better understand the benefits, trade-offs and options for NbS actions to effectively achieve mitigation outcomes, providing for more transparent and evidence-based decision-making.

2. Carbon accounting for nature-based solutions

2.1. Limitations of current accounting systems

Current carbon accounting systems and policy frameworks for land-use mitigation activities promote approaches that fail to consider

essential ecosystem characteristics that influence the longevity and stability of carbon stocks and their risk of loss. These failings can result in unintended and perverse mitigation outcomes. Current greenhouse gas (GHG) accounting under the UN Framework Convention on Climate Change (UNFCCC) (IPCC, 2014a) is based on flows from sources to sinks and limited to human activities. Current accounting for ecosystem services under the UN System of Environmental-Economic Accounting Experimental Ecosystem Accounting (SEEA EEA) (UN et al., 2014a) assigns the ecosystem service of climate regulation to be 'carbon sequestration', defined as a 'positive net annual carbon balance' and measured as a flow. Both the UNFCCC and SEEA EEA accounting approaches based on flows obscure the mitigation benefits of stable and resilient ecosystem carbon stocks and land management activities that protect, enhance or degrade them.

The current UNFCCC accounting system was developed for the purpose of providing information that would assist with mitigation policy and decision making for reducing emissions from fossil fuel use. However, there are three key issues that point to the need for an enhanced approach for carbon accounting in the land sector. First, the focus on carbon flows – usually net flows from emissions and removals – and not stocks creates incentives to maximise sequestration by planting trees and maintaining young forests with high rates of growth and carbon uptake. Second, the interdependence of carbon stocks and flows in ecosystems with other ecosystem processes means that an integrated accounting system incorporating a range of ecosystem services is needed to elucidate potential synergies and trade-offs. Hence, current accounting based on carbon flows does not reveal the greater mitigation benefit from protecting the larger, more stable and resilient carbon stocks in older forests that avoid the risk of carbon loss, as well as the opportunity cost of foregoing the carbon storage in natural ecosystems (Houghton, 2013; Keith et al., 2015). Not accounting for the benefits of long-term storage may in part explain the failure to significantly reduce deforestation and degradation of primary forests (Potapov et al., 2017). Third, we argue that a key criterion for prioritising mitigation activities and investments in the land sector should be minimising the risks of emissions. These risks are related to stability, resilience and longevity of the carbon stocks.

2.2. Role of carbon stocks and flows in mitigation

The objective of climate change mitigation is to stabilize and reduce GHG concentrations in the atmosphere (i.e. a stock), and as a corollary, to maximise carbon storage in the biosphere. The Paris Agreement states, "*Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of the greenhouse gases, including forests*" (UNFCCC Article 5 2015), that is, ecosystem carbon stocks. Additionally, the role of ecosystem processes in the conservation of carbon stocks is included, "*noting the importance of ensuring the integrity of all ecosystems, … and the protection of biodiversity*" (UNFCCC Preamble, 2015). REDD+ also notes the "*role of conservation … and enhancement of forest carbon stocks*" (UNFCCC Article 4.1d 2015, IPCC, 2014b). To operationalise these commitments, effective mechanisms and actions need to be agreed, documented and implemented (FAO, 2017; Funk et al., 2019; Lee and Sanz, 2017). Guidelines for revising the accounting rules were initiated with the Katowice Climate Package (UNFCCC, 2018) but much remains to be done.

The mitigation benefit of carbon storage refers to the retention of carbon stocks in reservoirs and hence the avoided release of carbon to the atmosphere. The benefits of carbon storage derive from the magnitude, longevity, stability and timing of the ecosystem carbon stocks (Ajani et al., 2013; Mackey et al., 2013). The magnitude of stocks depends on the net ecosystem carbon balance and the area of the ecosystem. Longevity refers to the time period during which the ecosystem carbon stock remains at a given level averaged across a landscape scale and inclusive of the effects of natural disturbance and regeneration. The stability of forest ecosystem carbon stocks depends on maintenance of ecosystem integrity in terms of the ecosystem's structure, composition and functioning which includes its resistance to external pressures, resilience (i.e. capacity for self-regeneration following perturbations) and adaptive capacity (De Souza et al., 2019). The timing refers to the fact that avoiding emissions now is better than future sequestration, from both a biosphere and atmosphere perspective. First, ecosystem carbon stocks are quickly depleted by land-use impacts but only slowly regained (Körner, 2003). Second, the cumulative global warming potential of carbon dioxide (CO_2) in the atmosphere is in the order of a century for about 60% of a unit of CO_2 emitted, but in the order of millennia for the remainder due to its long lifetime in the atmosphere and slow processes of removal through complete dissolution in the deep ocean (Archer and Brovkin, 2008; Archer et al., 2009). A future stable atmospheric CO_2 concentration will be determined by the total accumulated emissions over the preceding centuries and not by the contemporaneous balance between emissions and removals (Allen et al., 2009). Policies that limit further increases in the stock of atmospheric CO_2 are more effective mitigation actions, and therefore preferable, to those that merely limit the rate of net emissions (Allen et al., 2009). The estimated global carbon budget for a 66% probability of meeting the 1.5 °C global warming target is 115 Pg C; only 11.5 years of annual emissions at current levels (IPCC, 2018; GCP, 2019). Achieving this target requires global anthropogenic emissions to reach net zero by ~2050 against a 2010 baseline, and subsequently turn negative so that sequestration rates exceed emissions for many decades (Figueres et al., 2017; Millar et al., 2017). All mitigation activities to reduce and preferably avoid emissions, as well as increase removals, must be considered to meet this target.

It is now recognised that the global goals for mitigation cannot be met without a significant contribution from carbon storage in ecosystems, particularly forests as well as peatlands, wetlands and mangroves (IPCC, 2019a). NbS actions to maintain and increase carbon storage are estimated to have the potential to avoid more than 30% of global anthropogenic emissions (Federici et al., 2017; Lewis et al., 2019; Moomaw et al., 2019; Seddon et al., 2019a, 2019b). Mitigation strategies that avoid emissions by maintaining terrestrial ecosystem carbon stocks – which globally total 450 Pg C in vegetation (Erb et al., 2018) – achieves immediate mitigation benefits compared to sequestration by reforestation which takes a long time and assumes regenerative capacity. Potential increased carbon storage is estimated at 120 Pg C by ceasing deforestation and degradation of primary forests globally and allowing secondary forests to continue re-growing (Houghton and Nassikas, 2018).

2.3. Need for an enhanced carbon accounting system

It is now a critical time to re-consider the design of carbon accounting systems to provide information that can better inform policy and decision-making regarding prioritisation of NbS actions and the mitigation benefits and trade-offs between different forest management strategies. Information from carbon accounts is needed to assist governments in implementing the Paris Agreement by identifying options for all mitigation activities, assessing their relative benefits, and prioritising investments. The imperative is because major international organisations involved with the development and application of carbon accounting are currently undergoing revisions. Negotiations are continuing about the rules and guidance to implement the Paris Agreement by CoP 26 of the UNFCCC. The SEEA Experimental Ecosystem Accounting guidelines are currently under revision with the aim to develop a statistical standard by 2021.

To achieve the purposes of informing the policy objectives of international conventions and the statistical objectives of national accounting, we suggest enhancing current carbon accounting by incorporating stocks as well as flows into GHG inventories from the UNFCCC and integrating these within the accounting framework of the SEEA EEA. This enhanced accounting system records (i) changes (losses and gains) in

carbon stocks, and (ii) qualities of reservoirs in terms of the magnitude, stability and longevity of their carbon stocks that is related to the condition of the ecosystem. It is important to ensure that a revised and enhanced carbon accounting system is strengthened to incorporate benefits from the full suite of ecosystems services, and fit for the purposes of accounting for national emission reduction targets under the Paris Agreement. Using the SEEA accounting framework facilitates integration of accounts for carbon stocks and flows with other components of environmental-economic accounts. Environmental-economic accounts describe ecosystems and their links to economic and other human activity. These links reflect fundamental connections through dependencies of human activities on the condition and services provided by ecosystems, and conversely, the impacts of these activities on ecosystem condition and their future capacity to provide services. We use the term 'accounts' following the statistical definition from SEEA, meaning a systems approach to the organisation of data about stocks and flows that utilises accounting concepts, structures, rules and principles. This terminology differs from that in the UNFCCC (Grassi et al., 2018).

Using the accounting framework of the SEEA EEA as an information system will encourage and facilitate consistency in policy development across international conventions, as it uses comprehensive and mutually exclusive classifications, combines data from various sources, presents objective data, and in a policy relevant format. The benefit of these ecosystem-based accounts is their capacity to integrate data to evaluate NbS as mitigation activities, together with other land-use options and their trade-offs, as well as guidance for ongoing ecosystem management. This approach can provide information that supports a range of international commitments and related policies in addition to the Paris Agreement, including the Convention on Biological Diversity and the Sustainable Development Goals.

3. Material and methods

3.1. Carbon stocks and flows

The data presented in figures and tables are derived from intensive studies of carbon dynamics in wet, temperate eucalypt forest in southeast Australia; *Eucalyptus regnans* (Mountain Ash) forest in the Central Highlands of Victoria (Keith et al., 2017a) and *E. delegatensis* (Alpine Ash) forest in the South-Eastern Highlands of NSW (Keith et al., 2009). Various data sources have been integrated and re-analysed to fit the accounts format. The carbon stocks and flows in Fig. 4 represent all reservoirs (soil, biomass, products and residuals, atmosphere) quantified as tC ha^{-1}, and flows quantified as tC ha^{-1} $year^{-1}$ and assuming transfer between reservoirs within a vertical cylinder. The carbon content of the forest biomass was estimated conservatively as 600 tC ha^{-1} as an average for primary forest across the landscape, based on site measurements and modelling (Keith et al., 2017a). The carbon content of the atmosphere as the volume within the cylinder was calculated as a proportion of the carbon content in the vegetation, for illustrative purposes to show the relative differences between reservoirs. In the global carbon cycle, average carbon stocks in reservoirs are 550 Pg C in vegetation and 829 Pg C in the atmosphere (Keith et al., 2017a). Hence, the atmosphere is 150% of the vegetation, which is 900 tC ha^{-1} in our example. Note that this does not represent the average carbon content in the atmosphere for every hectare globally.

The total soil carbon content was measured in the *E. delegatensis* forest (251 tC ha^{-1} in the 0–200 cm soil profile, Keith et al., 2009), although this forest is slightly drier and less productive than the *E. regnans* forest, and so the soil carbon content used in Fig. 4 was estimated to be 300 tC ha^{-1}. The change in soil carbon content was estimated from reported reductions in organic carbon content in soils after logging and slash burning in similar forest ecosystems in Australia, principally from (Rab, 1994, 1996, 2004), and similar results from (Ellis et al., 1982; Ellis and Graley, 1983; May and Attiwill, 2003). Based on the data (Rab, 1994, 1996) for reductions in soil organic carbon concentration with differing degrees of soil disturbance (logged area, snig tracks, log landings, low, moderate and high fire intensity) and the proportion of the area within cutblocks of each disturbance level, the average was calculated

Table 1
Evaluation of current concepts and potential perverse outcomes from existing carbon accounting systems.

Current concepts	Potential perverse outcomes
1. Active forest management is needed to sustain the strength of the carbon sink.[a,b,c,d]	• Primary forests are logged to establish secondary forests or plantations.[e] • Stability and resilience of ecosystems are reduced. • Timing of sequestration is discounted, such that CO_2 removals in the near future are equated with removals in the distant future.
2. Emissions from forests are mainly due to deforestation where change in land-use occurs.[f]	• Decline in forest condition due to emissions from logging and regrowing forests where there is no change in land-use (i.e. forest degradation) are not appropriately accounted.[g]
3. Net annual ecosystem carbon balance is used as the metric for carbon sequestration.[h,o]	• Carbon stocks in all reservoirs are counted equally without consideration of the longevity or stability of the stock.[i] • Primary forests are logged to establish secondary forests or plantations if initial carbon stock loss is not counted adequately.[j]
4. Flows of carbon are equivalent from all reservoirs.[f]	• Carbon stored in short-term high-risk reservoirs (e.g. plantations) is counted as equivalent to long-term stable reservoirs (e.g. primary forests).
5. Definition of 'forest' is based on tree height, cover and area of the potential land-use.[f]	• Primary forests are logged to establish secondary forests or plantations, and this can include bare ground during a rotation.[k]
6. Mitigation requires activities to reduce emissions or increase sequestration from a business-as-usual baseline.[f,l,m,q]	• Incentives are provided to countries that have degraded forest carbon stocks (or are expected to) which hence have the potential for storage, but incentives are not provided to maintain and protect existing carbon stocks in natural ecosystems.
7. The reference level is the current carbon stock or a temporal baseline.[f,l,m]	• Carbon storage potential (difference between current stock and carbon carrying capacity) cannot be assessed.[n]
8. Net carbon flows from anthropogenic activities are reported.[f]	• Attribution of gross flows to human and natural causes is not possible.[i] • The reporting of net flows is not equivalent to the resultant change in atmospheric concentration.
9. Mitigation activities are counted over a limited time period e.g. 20 or 100 years[o,p]	• Carbon stocks of different longevities are considered fungible, resulting in the long-term residence of CO_2 in the atmosphere not being accounted.

[a] Nabuurs et al. (2007).
[b] Nabuurs et al. (2017).
[c] Cias et al. (2008).
[d] Canadell and Raupach (2008).
[e] Keith et al. (2014).
[f] IPCC (2014b).
[g] Mackey et al. (2015).
[h] UN et al. (2014a).
[i] Ajani et al. (2013).
[j] Mackey et al. (2013).
[k] Dooley and Stabinsky (2019).
[l] FAO (2017).
[m] Lee and Sanz (2017).
[n] Keith et al. (2010).
[o] IPCC (2006).
[p] IPCC (2019b).
[q] Global Forest Observation Initiative (2016).

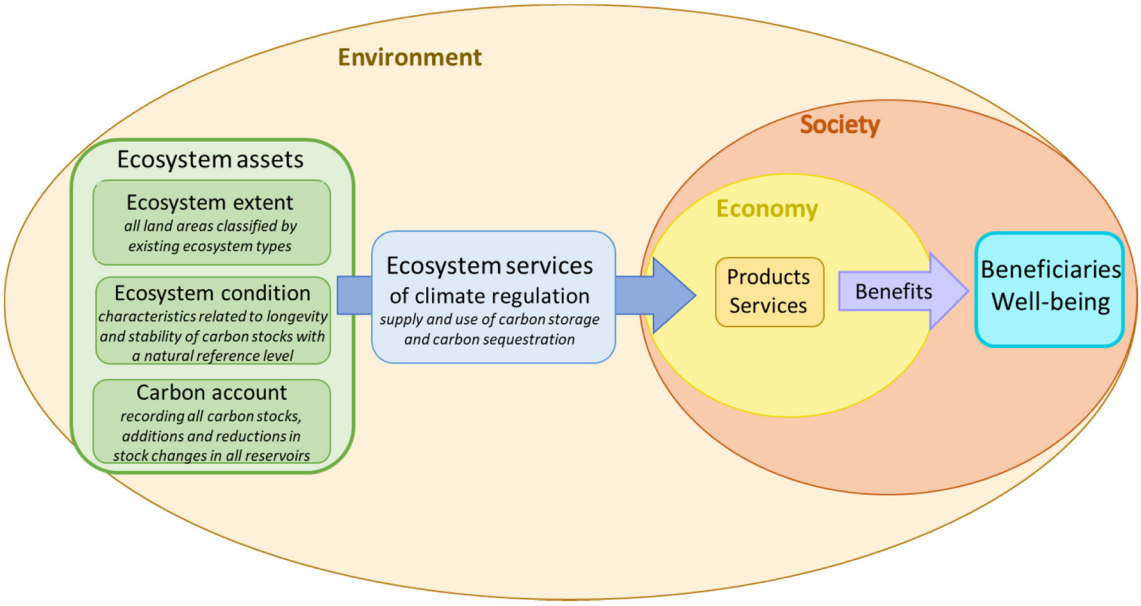

Fig. 1. Conceptual approach for the proposed accounting for carbon stocks and stock changes, and the ecosystem services of carbon storage and sequestration. The context is the ecosystem accounting framework where the subsets of the economy and society exist within the environment. Ecosystem assets are described in terms of their extent and condition, and in this case related to the carbon stock account. The ecosystem service of global climate regulation represents the supply and use of carbon storage and carbon sequestration that provide benefits within the economy and society.

for the whole area of the coupe to be 40.2% reduction in 0–10 cm soil depth. Soil carbon content in the 0–10 cm depth was calculated as 24% of the whole soil profile to 200 cm depth, based on the soil carbon profile data from the *E. delegatensis* forest (Keith et al., 2009). Loss of carbon was assumed to occur only in the 0–10 cm depth. Hence, the loss of carbon from the whole soil profile was calculated to be 10% of the total soil carbon content. This is similar to the average of 8% reduction due to logging estimated from a global meta-analysis of temperate forests (Nave et al., 2010).

The transfers of carbon from logged primary forest to products, residuals and emissions in the secondary and plantation forests are calculated from proportions and emissions factors through the product life cycle (Keith et al., 2015). Annual fluxes of carbon between the biosphere and atmosphere, calculated as the net carbon balance between photosynthesis and respiration, are derived from the integration of chamber measurements of tree biomass components and flux tower measurements in the *E. delegatensis* forest (Keith et al., 2009).

3.2. Accounting tables

The proposed carbon accounting framework is illustrated for the case study forest region in the Central Highlands of Victoria, Australia. It includes: (i) comprehensive carbon stock and flow accounts using ecosystem types classified by qualities of the reservoirs (Table 3), and (ii) integrated accounts of the supply and use of ecosystem services, products and residual using the ecosystem type classification (Table 4). These data have been re-analysed for recording as ecosystem account tables for the purpose of demonstrating, in theory and practice, how both stocks and flows of carbon can be presented in a format useful for informing policy about benefits for climate mitigation and forest management.

Data sources for the proportions of the total carbon stock in native forest (Fig. 5A) that are transferred to different pools and lost as emissions, are derived from a life cycle analysis (Keith et al., 2015). Proportions of the total carbon stock in hardwood (Fig. 5B) and softwood plantations (Fig. 5C) that are transferred to different pools and lost as emissions, are derived from the national inventory report (Australian Government, 2019). Carbon stocks and annual stock changes were calculated for five forest types: (i) protected native forest, (ii) logged native forest, (iii) hardwood plantation, (iv) softwood plantation, and (v) other land cover types within the Central Highlands study region as the ecosystem accounting area (Keith et al., 2017a, 2017b). These data are reported for ecosystem services in (i) forest available for logging, and (ii) forest areas not available for logging, as the management status of these forests is a key policy issue. The ecosystem services are (i) carbon sequestration as an annual stock change or flow, and (ii) carbon storage or the standing stock of carbon. These two ecosystem services are supplied by the environment based on a classification of land cover spatial units. The ecosystem services are used by economic units classified by industries. Carbon sequestration and storage in secondary forests available for logging are used by the forestry industry. Carbon sequestration and storage in conservation or protected forests are a collective good, and hence are assigned as a use by government in the accounts.

The atmosphere is considered a separate asset and hence flows of carbon are recorded between the biosphere and atmosphere. The stock of carbon in the atmosphere is calculated as the proportion of the total global stock of carbon in the atmosphere (843 Pg C) (IPCC, 2013), divided by the surface area of the Earth (51.01 billion ha), multiplied by the area of the ecosystem accounting area (735,655 ha) (Keith et al., 2017a). This represents the average carbon stock in the atmosphere above a landscape of different vegetation types and is not in proportion to the carbon stock in the vegetation (as in Fig. 4).

4. Results

4.1. Proposed carbon stock and flow accounting framework

Our proposed enhancements to carbon accounting are based on evaluation of current approaches, with the concepts applied under the UNFCCC and SEEA EEA, but revealing their potential for perverse outcomes (Table 1). From this basis we derived a framework for holistic and comprehensive accounting of carbon stocks and flows that meets the statistical standards required for environmental-economic accounting and provides the information relevant to support decisions

regarding NbS actions for mitigation under the Paris Agreement. The conceptual approach to accounting for carbon stocks and stock changes, and the ecosystem services of carbon storage and sequestration are illustrated in the context of the ecosystem accounting framework (Fig. 1).

Ten essential components are required to extend current accounting systems for the land sector and fulfill the requirements of the ecosystem accounting framework (Table 2). Comprehensive coverage allows calculation of the conservation of mass for carbon within the closed global carbon cycle, including all stocks, changes, areas and causes; this is an important theoretical criterion for accounting. All land areas are recorded and spatially referenced, irrespective of degree of human management, without distinguishing managed and unmanaged lands. The benefits of carbon storage in all ecosystems are recognised and net carbon stock change represents the total exchange between biosphere and atmosphere. Reporting all gross flows as emissions and removals allows identification of factors driving change in stocks, and hence the consequences of management interventions. For example, gross flows show the potential for growth and increased carbon storage in natural forests through enabling secondary forests to regrow naturally (an approach to forest management called proforestation, Moomaw et al., 2019) and thus increase relatively stable, long-lived stocks (Houghton, 2013; Richter and Houghton, 2011; Seddon et al., 2019a, 2019b). This potential benefit is hidden in current accounting that reports the net analysis of emissions and removals from land-use, whereas here, removals of carbon (sequestration) are treated separately from emissions reductions, so that sequestration is not considered an offset. All disturbances, natural and anthropogenic, can cause changes in carbon stocks and so are recorded as additions and reductions in asset accounts. This comprehensive approach accounts for what occurs in the atmosphere and in the biosphere. The 'user' or beneficiary of the ecosystem service of the total carbon storage in the biosphere is the general public when emissions to the atmosphere have been avoided. Attribution of causes of stock changes, due to natural or anthropogenic disturbances and whether the human activities are additional, can be achieved as a second stage within the accounts, facilitated by disaggregation of ecosystem types by their qualities as reservoirs, and linking to supply and use of services and beneficiaries. This attribution provides important information for management, and prioritisation in NDCs.

Table 2
Essential components of the proposed carbon accounting for the land sector.

Essential components	Description
1. All land areas and the ecosystems that occur	• Land and associated ecosystems are classified by extant ecosystem types irrespective of degree of human management • All ecosystems provide benefits of carbon storage and require some management • Carbon stock change represents the total exchange with the atmosphere • Spatially referenced to allow attribution of stocks and flows
2. All carbon pools	• Above- and below-ground biomass, dead standing biomass, coarse woody debris, litter, soil carbon, and aqueous carbon (dissolved and particulate organic carbon)
3. Quality or condition of carbon stocks	• Stability, magnitude, longevity, time required for restoration, and resilience related to risk of loss • Differentiation by classification of ecosystem types and characteristics of their condition as reservoirs of carbon • Capacity to produce the ecosystem service of climate regulation • Decline in condition is reflected as a reduction in the asset (stock) quality
4. Definition of 'forest'	• Refers to the actual vegetation cover at the time of accounting • Includes components of forest structure, carbon stocks and biodiversity
5. Biosphere and atmosphere	• Distinguished as separate spatial units in a three-dimensional delineation of the accounting system • All stocks and flows between the biosphere, atmosphere and economy are counted
6. Reference level	• Natural condition that represents ecosystem integrity, and underpins the carbon carrying capacity, is used to assess changes in carbon stocks • Initial loss of carbon from a natural ecosystem and historical changes are counted • Scenarios using any other baselines or counterfactuals must be explicit
7. Recording gross flows	• All sources of emissions and removals are transparent • Gross flows show the carbon restoration potential from proforestation.
8. Permanence of carbon stocks	• Permanence used as a criterion in accounting • All stock changes reported against a single reference level of the natural condition
9. Natural and anthropogenic disturbances	• All carbon stock changes attributed as additions and reductions in asset accounts
10. Ecosystem service of climate regulation	• The contribution of the magnitude and longevity of carbon stocks in the biosphere to reducing the concentration of CO_2 in the atmosphere • The benefit of the carbon stock in the biosphere depends on the ecosystem condition or quality of the reservoir

4.2. Theoretical basis for ecosystem services of carbon storage and sequestration

It is important that when accounting for land carbon the mitigation benefits arising are treated as one of a suite of ecosystem services. In this case, the benefit is a decrease, or avoided increase, in the atmospheric CO_2 stock. In ecosystem accounting terms, the general ecosystem service provided from forest-based mitigation actions is referred to as 'climate regulation' (CICES, 2016). Expert opinion is divided on whether climate regulation should include measurements of both carbon sequestration (net annual carbon balance as a removal from the atmosphere) and carbon storage (avoided loss of carbon stock from the biosphere) (IPCC, 2019a) (Fig. 2). Here we propose that both should be included. In which case, a social value is placed on those ecosystem processes, including the functional role of biodiversity, that underpin the storage and sequestration of carbon. The concept of carbon storage as an ecosystem service, and avoiding carbon being emitted to the atmosphere, can be explained as a fund-service relationship when a resource is used but not transformed (Daley and Farley, 2011). A flow of services that provide benefits are gained by the existence and condition of the asset (in this case, an ecosystem), and this is distinct from a physical change in the asset.

4.3. Practical demonstration of the carbon accounting framework using a case study

Our proposed carbon accounting framework, illustrated here using data from a case study of the wet, temperate eucalypt forest in southeastern Australia, includes: (i) comprehensive carbon stock accounts using ecosystem types classified by qualities of the reservoirs in relation to ecosystem condition (Table 3), and (ii) integrated accounts of the physical supply of ecosystem services of carbon storage and sequestration from environment units, and use by economic units, and transfer to products (Table 4).

The format of the carbon stock account (Table 3) provides an ecologically based representation of the carbon cycle. Opening and closing stocks of carbon are recorded with additions to, or reductions in, the stocks. Reservoirs are classified according to differences in qualities of the carbon stocks in terms of their magnitude, stability and longevity. All ecosystem types are included with differentiation of terrestrial biocarbon as natural ecosystems, semi-natural ecosystems, plantations (classified as tree crops) (FAO, 2018) and agriculture. In contrast, the existing GHG inventory reporting include flows from geocarbon

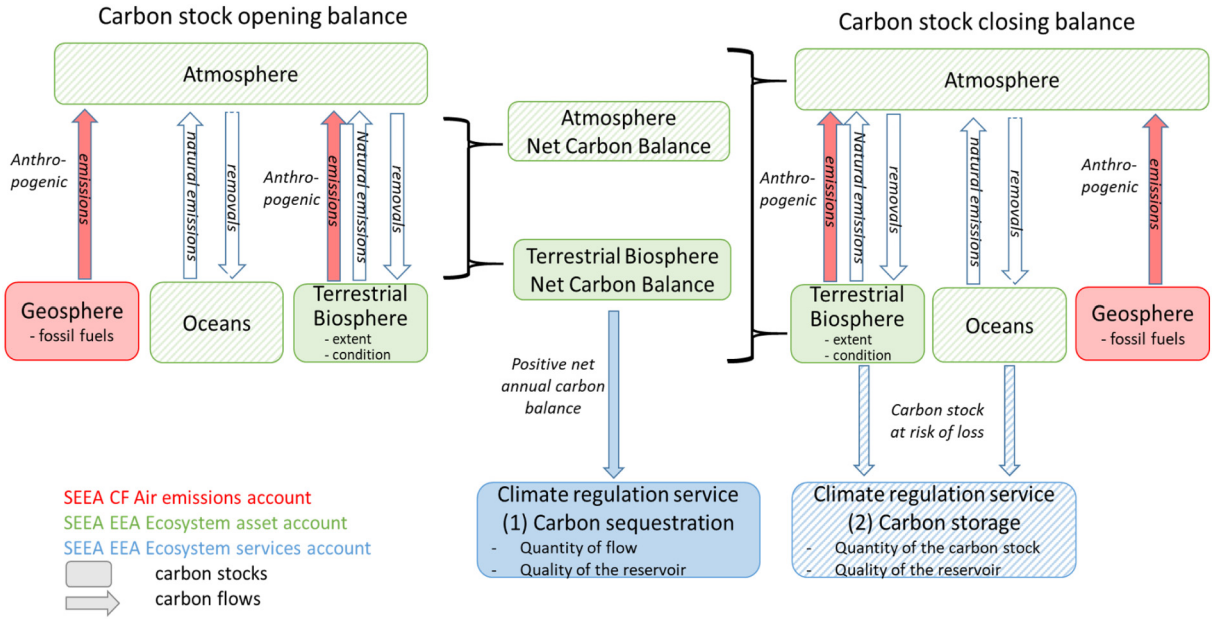

Fig. 2. Ecosystem accounting framework showing the stocks and flows of carbon. The ecosystem asset account consists of carbon stocks in the terrestrial biosphere in the SEEA EEA (green shaded), and this should be extended to include stocks in the oceans and atmosphere (green hatched), and geosphere (red shaded). Ideally, the asset account should also include stocks held within the economy (Ajani et al., 2013) but this extension is not required for the purposes of this paper. The asset account consists of carbon stocks and stock changes over time from the opening balance to the closing balance. Stock change is calculated as the net ecosystem carbon balance, which represents a flow. Gross flows between stocks (or reservoirs of carbon) include anthropogenic and natural emissions, and removals by plant uptake. The ecosystem service is climate regulation. This framing also allows for the atmosphere to provide a sink service with respect to anthropogenic emissions. Appropriate measured components of climate regulation depend on the purpose of the accounts, the ecosystem types and management activities. Components of the ecosystem service include (i) carbon sequestration (blue shaded) equal to the positive net annual carbon balance; and (ii) carbon storage (blue hatched) equal to the avoided loss of carbon. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and net flows from biocarbon in semi-natural ecosystems, plantations and agriculture, but not in natural terrestrial, aquatic and marine ecosystems.

In the example account table (Table 3), the terrestrial biocarbon section has been expanded to show an ecosystem type classification that denotes differences in the qualities of reservoirs under different forest management types. Forests are ecosystem assets and their management types are delineated as spatial areas that reflect the locations at which management activities occur. Recognising transfers of carbon between these reservoirs makes changes in the quality of the stocks transparent, and hence additions and reductions in stocks can be attributed to natural or human factors. Recording changes in stocks over time is a critical inclusion in ecosystem accounts allowing assessment of long-term benefits from ecosystems. Recording the qualities of reservoirs allows assessment of the differences in risk of loss of carbon. In the context of climate change mitigation, the benefit from maintaining primary forests avoids transfer to the atmospheric stock and increases longevity of the ecosystem stock. Hence, quantification requires metrics of magnitude and longevity (Körner, 2017).

The ecosystem service supply and use tables use detailed data from the forest region in south-eastern Australian (Table 4) to show the format of the account tables with transfers between supply and use. This table shows the ecosystem services from the Experimental Ecosystem Accounts (UN et al., 2014a) and products and residuals as emissions from the Central Framework (UN et al., 2014b). These accounts show the flows of carbon from the environment and use by economic units, and the flows of products and emissions through different industries within the economy. The flows of carbon are shown diagrammatically for native forests, hardwood and softwood plantations in Fig. 3 and shown in accounts in Table 4.

Tree growth increment that provides wood volume is the ecosystem service in ecosystem accounting. In a native forest, growth increment is recorded at the end of rotation at harvest maturity, whereas growth is recorded annually for a plantation. The production boundary, which differentiates accounting within the environment from that within the economy, occurs with the activity of logging the forest. Accumulation in the forest is calculated as the difference between annual increments and logged volume plus waste. A positive difference represents a supply to the inventory, whereas a negative difference represents a use of the standing stock. The atmosphere is considered to supply an ecosystem service as a carbon sink. This service is used by the economic units that produce emissions of CO_2 from fire, logging and processing. Annual biomass increment is apportioned according to the volumes of sawlogs and pulplogs produced from each forest type. The forestry industry supplies sawlogs and pulplogs that are used by wood and paper product manufacturing. Manufacturing supplies sawn timber and paper products that are used by other industries, such as construction, and emissions during processing are supplied by manufacturing and used by the atmosphere. Other industries supply timber and paper products that are used by households. At the end-of-life of products, households supply waste that is used by waste management.

The ecosystem service supply and use table is divided into quadrants to differentiate economic units and environment units, and supply or use of ecosystem services and products. Ecosystem services supplied by environment units include both carbon storage and carbon sequestration in the biosphere, and the carbon sink in the atmosphere. Products including sawlogs and pulp are supplied by economic units. The ecosystem services are used by economic units, mainly forestry industry and government, and products are used by economic units along the value chain.

4.4. Application of carbon accounting to prioritise nature-based solutions

Data from the accounts of carbon stocks and flows in the case study are used as an example of how NbS could be prioritised by assessing scenarios of forest management strategies in terms of their mitigation

Table 3
Comprehensive carbon accounting table using ecosystem types classified by qualities of the reservoirs and showing stocks and stock changes. The terrestrial biocarbon section has been expanded to show an ecosystem type classification that denotes differences in the qualities of the reservoirs in terms of the magnitude, stability, longevity and risk of loss of carbon stocks.

			Biocarbon														Total Biocarbon	Geocarbon
					Terrestrial													
					Natural ecosystems					Semi-natural ecosystems				Plantations		Agriculture		
	Atmosphere	Oceans	Aquatic	Marine	Rainforest	Protected Native Forest	Woodland/ Shrubland	Peatlands	Selectively harvested rainforest	Harvested native forest	Grazed woodland	Drained peatland	Hardwood	Softwood	Annual	Perennial		
Opening stock of carbon ($C\ t_0$)	12.139					111.570	0.322			30.210			4.258	0.577	0.037	0.211	147.185	
Additions to stock																		
Natural expansion (growth)	0.010					1.368												
Managed expansion (growth)	0.479									0.632			0.116	0.008				
Discoveries																		
Upward reappraisals																		
Reclassifications																		
Total additions to stock	0.489					1.368				0.632			0.116	0.008			2.124	
Reductions in stock																		
Natural contraction (emissions)						0.008				0.002								
Managed contraction (emissions)										0.414			0.041	0.024				
Managed contraction (harvest transfer)										0.181			0.087	0.048				
Downward reappraisals																		
Reclassifications																		
Total reductions in stocks						0.008				0.597			0.128	0.072			0.805	
Closing stock of carbon ($C\ t_1$)	12.628					112.930	0.322			30.245			4.246	0.513	0.037	0.211	148.504	
Net ecosystem carbon balance ($C\ t_1$ - $C\ t_0$)						1.360				0.035			-0.012	-0.064			1.319	

Table 4
Integrated account of ecosystem service supply and use of carbon sequestration and carbon storage, products and emissions. Data for the Central Highlands ecosystem accounting area average annual MtC over 2011–2015. Quadrants A to H show the classifications by units and services. Industry classification: (i) agriculture, forestry and fisheries, (ii) wood and paper product manufacturing, (iii) other industries, (vi) households, (v) waste management, (vi) government. Ecosystem classification: (a) protected native forests, (b) logged native forests, (c) hardwood plantations, (d) softwood plantations, (e) woodlands, (f) grasslands. Supply of ecosystem services by environment units is shown by the classification of ecosystem assets, including the quality of the reservoir of the carbon stock (quadrant B). The supply of products by economic units includes all goods and services produced in the economy according to an industry classification (quadrant C). The use of ecosystem services by type of economic units includes both use of services as input to further production and use of services for final consumption (quadrant E). The use of ecosystem services by other environment units, which would represent intermediate ecosystem services, are not included in the existing SEEA guidelines (quadrant F). Products are used by different economic units in a series of industry classes (quadrant G). Grey shaded quadrants have no data by definition. Coloured cells show the transfer of carbon from supply to use of the ecosystem service.

PHYSICAL SUPPLY

	Economic Units										Environment Units: Biosphere									Environment Units	
	Agriculture, Forestry & Fisheries	Wood & paper product manufacturing	Other Industries (construction)	Households	Waste management	Energy	Government*	Inventory	Imports	Protected native forest	Woodland/ Shrubland	Harvested native forest	Hardwood plantation	Softwood plantation	Crops and horticulture	Grassland	Total biosphere	Atmosphere	TOTAL SUPPLY
Ecosystem Services																			
Carbon sequestration										1.368		0.632	0.116	0.008			2.124		2.124
Carbon storage										111.570	0.322	30.210	4.258	0.577	0.037	0.211	147.185		147.185
Carbon sink																		0.796	0.796
Products																			
Sawlogs-native forest	*0.050*	*0.018*	*0.018*	*0.005*				*0.035*											*0.126*
- plantation hardwood	*0.002*	*0.001*	*0.001*	*0.003*															*0.007*
- plantation softwood	*0.031*	*0.022*	*0.022*	*0.0002*															*0.075*
Total Logs	0.083	0.041	0.041	0.008				0.035											0.209
Pulp - native forest	*0.131*	*0.091*	*0.091*																*0.313*
- plantation hardwood	*0.085*	*0.060*	*0.060*																*0.205*
- plantation softwood	*0.017*	*0.012*	*0.012*																*0.041*
Total Pulp	0.233	0.163	0.163																0.559
Total Products	**0.316**	**0.204**	**0.204**	**0.008**				**0.035**											**0.767**

PHYSICAL USE

	Economic Unit										Environment Units: Biosphere									Environment Units	
	Agriculture, Forestry & Fisheries	Wood & paper product manufacturing	Other Industries (construction)	Households	Waste management	Energy	Government*	Inventory	Imports	Protected native forest	Woodland/ Shrubland	Harvested native forest	Hardwood plantation	Softwood plantation	Crops and horticulture	Grasslands	Total biosphere	Atmosphere	TOTAL USE
Ecosystem Services																			
Carbon sequestration	0.756						1.368												**2.124**
Carbon storage	35.293						111.892												**147.185**
Carbon sink																			
Harvested forest (native + plantation)																			
- emissions from fire	*0.006*																		*0.006*
- emissions from harvesting	*0.479*																		*0.479*
- emissions from processing		*0.112*		*0.195*															*0.307*
Protected native forest																			
- emissions from fire							*0.004*												*0.004*
Total emissions	0.485	0.112		0.195			0.004												**0.796**
Products																			
Sawlogs-native forest		*0.050*	*0.018*	*0.018*	*0.005*														*0.092*
- plantation hardwood		*0.002*	*0.001*	*0.001*															*0.004*
- plantation softwood		*0.031*	*0.022*	*0.022*				*0.025*											*0.100*
Total Sawlogs		0.082																	0.082
Pulp - native forest		*0.131*	*0.091*	*0.091*															*0.312*
- plantation hardwood		*0.085*	*0.060*	*0.060*															*0.205*
- plantation softwood		*0.017*	*0.012*	*0.012*				*0.014*											*0.055*
Total Pulp		0.233																	0.233
Total Products		**0.316**	**0.204**	**0.204**	**0.005**			**0.039**											**0.767**

benefits. We used a reference level of the forest's natural condition (i.e. primary forest (FAO, 2015)) to evaluate the relative benefits of current carbon storage and future storage under three scenarios: (a) primary native forest managed for conservation and long-term carbon storage; (b) secondary native forest managed for commodity production but largely dependent on natural regeneration; and (c) plantation forest managed for commodity production (Fig. 4).

Changing forest management by converting primary forest to secondary forest and then to a plantation results in a reduction in carbon stock in the forest ecosystem and increase in the atmosphere's carbon stock. Yet, the annual net flow shows a higher rate of carbon sequestration in the secondary forest and plantation (5 tC ha^{-1} $year^{-1}$) than in the primary forest (1 tC ha^{-1} $year^{-1}$). Emissions result from conversion of primary forest to secondary forest (330 tC ha^{-1}), and from secondary forest to plantation (180 tC ha^{-1}). However, these emissions have sometimes not been included in accounts if they occurred before the recording period. Hence, the carbon storage potential of the secondary forest cannot be determined.

Carbon storage is represented by the long-term average carbon stock in an ecosystem at a landscape scale, irrespective of temporal variability in emissions and removals and spatial variability due to disturbance or climate variability. The average carbon stock is a function of the prevailing environmental conditions, land-use, and natural and anthropogenic disturbance regimes. Changes in stocks are equivalent to flows between reservoirs when accounted over appropriate temporal and spatial scales (Houghton et al., 1999), and this is demonstrated for the stock changes between ecosystem types and the atmosphere.

Currently, the accounting periods used for calculating net carbon flows and changes in human activities (~20 years (IPCC, 2014a)) do not capture historic carbon losses (such as the impacts from initial logging of primary forest), or longer-term land-use impacts such as an 80-year logging rotation. Consequently, the full impact of changes in land-use are not incorporated and the carbon storage potential – the difference between the primary forest and current carbon stock – cannot be estimated. As illustrated in Fig. 4, primary forest conservation results in the largest, most stable and resilient store of carbon in the biosphere.

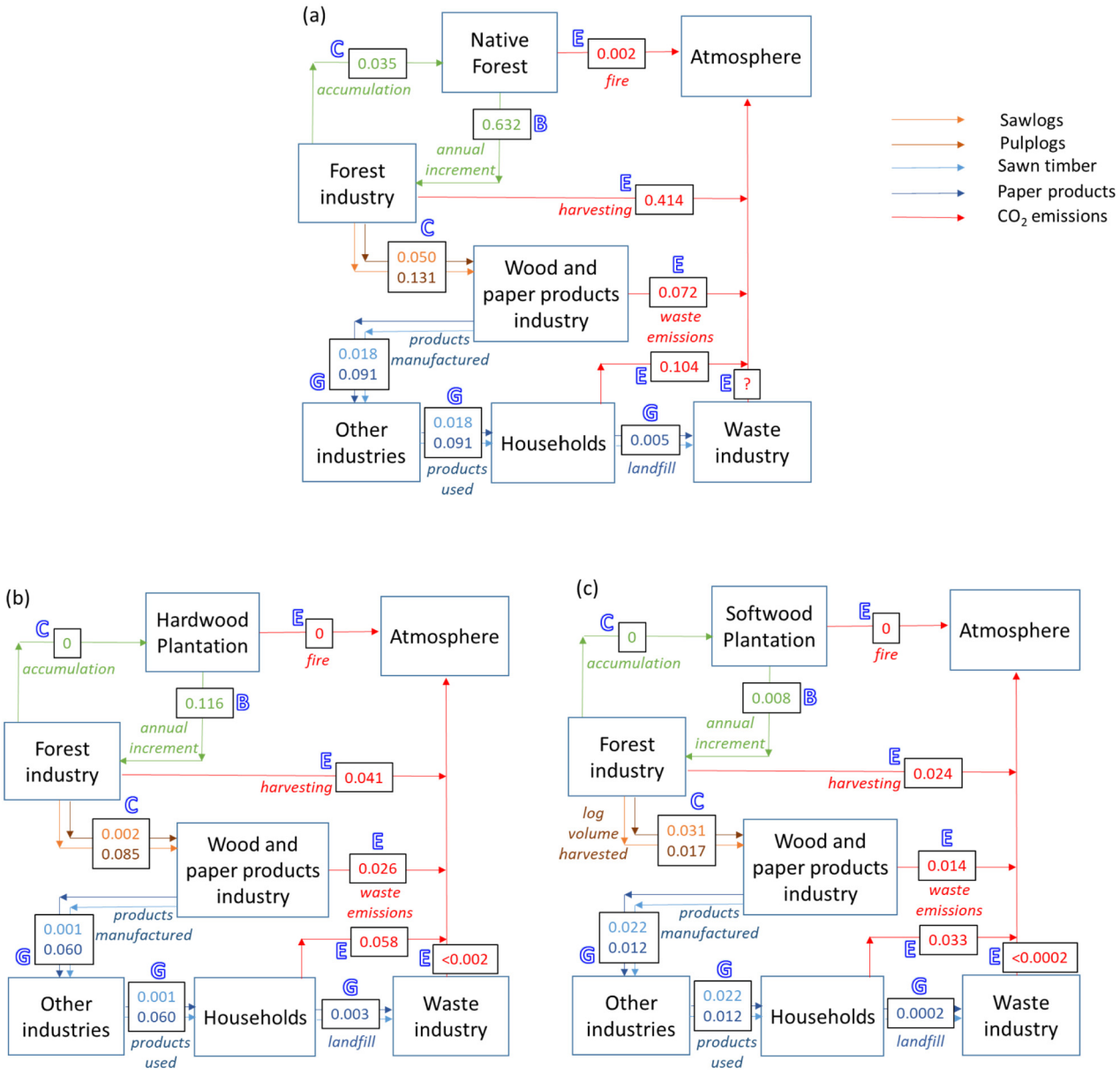

Fig. 3. Flows of carbon (Mt C) within the Central Highlands forest region from the environment to the economy as harvested wood products. Data are transferred to the accounts in Table 4 for each quadrant (labelled with blue letters). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4.5. Demonstrating the influence of accounting rules on mitigation outcomes

Results from the ecosystem service accounts demonstrate how the accounting rules may influence their interpretation for management decisions and hence prioritising NbS. Assessing the benefits of forests for the ecosystem service of climate regulation depends on which forest areas are included (managed, logged or conservation), whether gross or net flows are assessed, and whether both stocks and flows are assessed. Data for all these components are included in the example account tables and results for three forest management types are illustrated in Fig. 5.

Relative growth rate is highest in secondary forest managed for commodity production, but carbon storage is higher in primary forest (average 511 tC ha^{-1}) than in secondary forest (average 368 tC ha^{-1}). If carbon sequestration is defined as additions by forest growth, or relative growth, then it is positive in secondary forest, but if it is defined as net carbon exchange then it is only a small positive value (Fig. 5A). This result, however, masks the fact that in areas that have been logged and are regrowing, net carbon exchange is mostly negative due to the emissions from logging, even though additions by forest growth are positive and relative growth rate is highest (Fig. 5B). In the primary forest managed for conservation, net carbon exchange is positive for all time periods, even after a major wildfire, although relative growth rate is lower than in the secondary forest (Fig. 5C).

5. Discussion and conclusions

5.1. Informing land management decisions

Accounting for all carbon stocks and flows in all land areas and reservoirs means that assessment of changes within the closed carbon cycle is comprehensive. Presenting the ecosystem services of carbon storage and sequestration separately in the accounting supply and use tables makes their distinct benefits transparent. Integration of these regulating services with other ecosystem services within the ecosystem

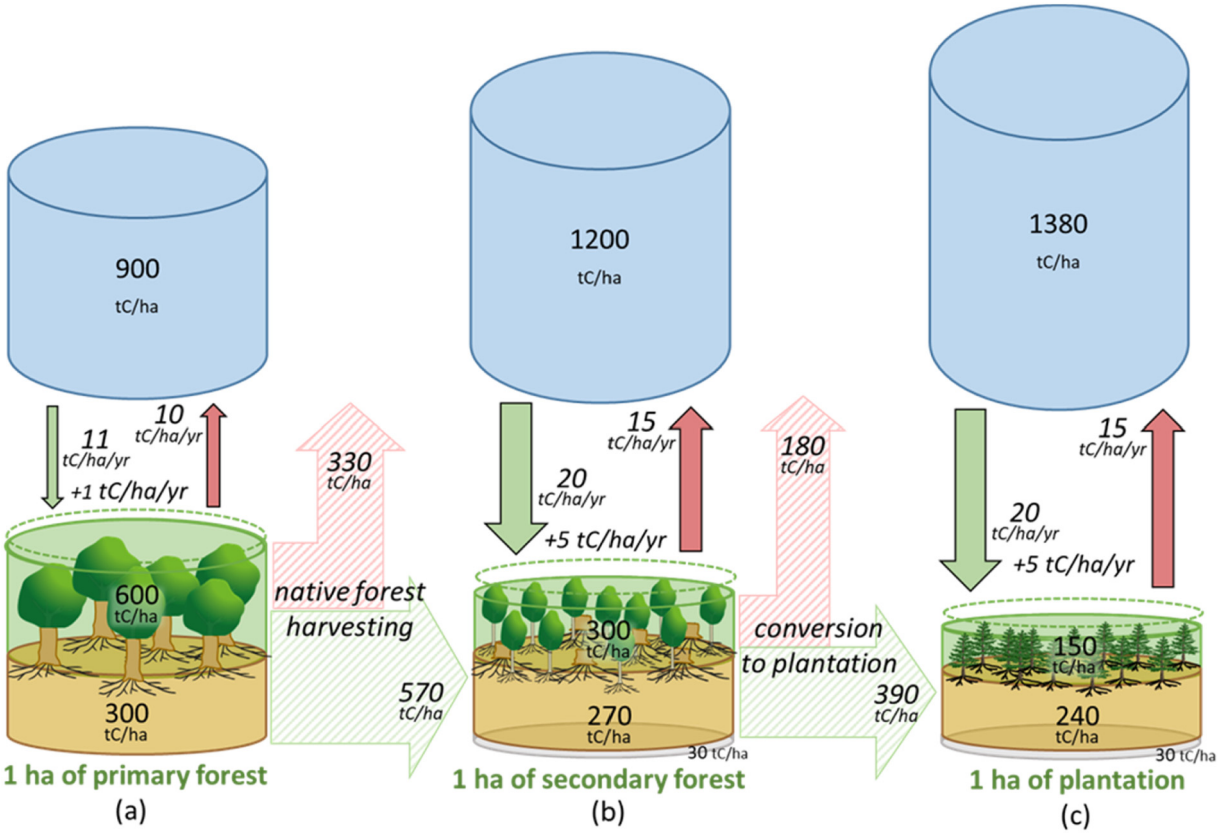

Fig. 4. Carbon stocks and flows in a wet, temperate eucalypt forest in south-eastern Australia as long-term averages at the landscape scale. Three forest management scenarios are depicted: (a) primary native forest managed for conservation; (b) secondary native forest managed for commodity production; (c) plantation forest managed for commodity production. Carbon stocks (roman type; tC ha^{-1}) are shown in three forest ecosystem reservoirs: (i) soil – brown; (ii) biomass – green; and (iii) wood products and residuals – grey; as well as (iv) atmospheric carbon stock - blue. Annual net flows (italic type; tC ha^{-1} $year^{-1}$) show removals by photosynthesis (solid green arrows) and emissions by respiration (solid red arrows). Conversions of forest management types result in emissions (red hatched arrows) and transfers from primary forest to secondary forest and to plantations (green hatched arrows). Transfers of carbon between reservoirs of the biosphere and atmosphere are depicted as occurring within the vertical cylinder. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

accounting framework is essential to allow comparisons among services and analyses of trade-offs. For example, including carbon stocks as well as flows, and their relationship to the condition and stability of ecosystems in the accounts, allows estimation of the carbon storage opportunity cost of land conversions (Golub et al., 2009; Searchinger et al., 2018) and the potential foregone carbon sequestration (Maxwell et al., 2019) due to land management activities. New insights revealed by the addition of components to create a holistic and comprehensive carbon accounting framework are summarised in Table 5 using examples from the case study forest region and compared with the potential for missing information under current accounting rules.

Comprehensiveness of the accounting framework is fundamental to allow all potential ecosystem services, with benefits now or in the future, to be identified and evaluated. Land management activities proposed as NbS can be evaluated using data describing carbon stocks and flows, together with data describing other ecosystem services and aspects of ecosystem condition. This integrated information allows alternative actions to address climate change to be compared in a holistic way in terms of effects on overall ecosystem condition and the mix of ecosystem services.

The study of the Central Highlands of Victoria, Australia (Keith et al., 2017a, 2017b) investigated a range of ecosystem services, produced by a predominately forested area, including carbon storage and sequestration reported here. The volume and value of the ecosystem services were estimated and revealed the relative importance of these current services. It also enabled an assessment of trade-offs between the supply of different services under alternative management scenarios.

5.2. Supporting international policy

Designing a holistic and comprehensive framework for carbon accounting is imperative to better inform negotiations for revisions of accounting systems (UN et al., 2014a) and policies and actions for climate mitigation and biodiversity protection (IPCC, 2019a). The information in carbon accounts can help prioritise the most effective mitigation activities, assess progress towards targets for increasing carbon storage in the terrestrial biosphere, and hence reducing the carbon concentration in the atmosphere, and guide effective integration of actions to address biodiversity loss and climate change as called for by the UNFCCC (2019b). The policy objective of the enhancement and conservation of carbon stocks can create financial value for carbon stored in forests and other carbon-dense ecosystems, and thus incentivise avoiding carbon stock loss (Wilder et al., 2014). An accounting framework that is comprehensive of all reservoirs and their carbon stocks and flows, allows selection of the most appropriate information for different purposes to enhance policy options for climate change mitigation.

Integrating the ecosystem services of carbon sequestration and carbon storage within the SEEA ecosystem accounting framework enables evaluation across a range of ecosystem services in determining benefits and identifying trade-offs. In managing land use activities, maximising carbon stocks in ecosystems should aim to be complementary with the provision of other ecosystem services, not detrimental. The relationship between carbon stocks and biodiversity is complex and varies between ecosystems and biomes, and as such should be assessed at the local and landscape scales relevant for management (Poorter et al.,

2015; Sabatini et al., 2018). For example, protecting and restoring existing natural ecosystems should be beneficial for most ecosystem services. In contrast, changing extant land use to increase carbon stocks, for example, by afforestation, may be detrimental to provision of ecosystem services including biodiversity from long-term human-modified ecosystems, such as grasslands and heathlands, or other natural ecosystems, such as peatlands. In addition, the criteria for assessing carbon storage by the condition of the reservoir include the role of biodiversity and ecological integrity which contribute to the longevity and stability of the carbon stock (Seddon et al., 2019b). Combining these data for various ecosystem services within the ecosystem accounting information system reveals these potential trade-offs and facilitates informed decision-making about land use change.

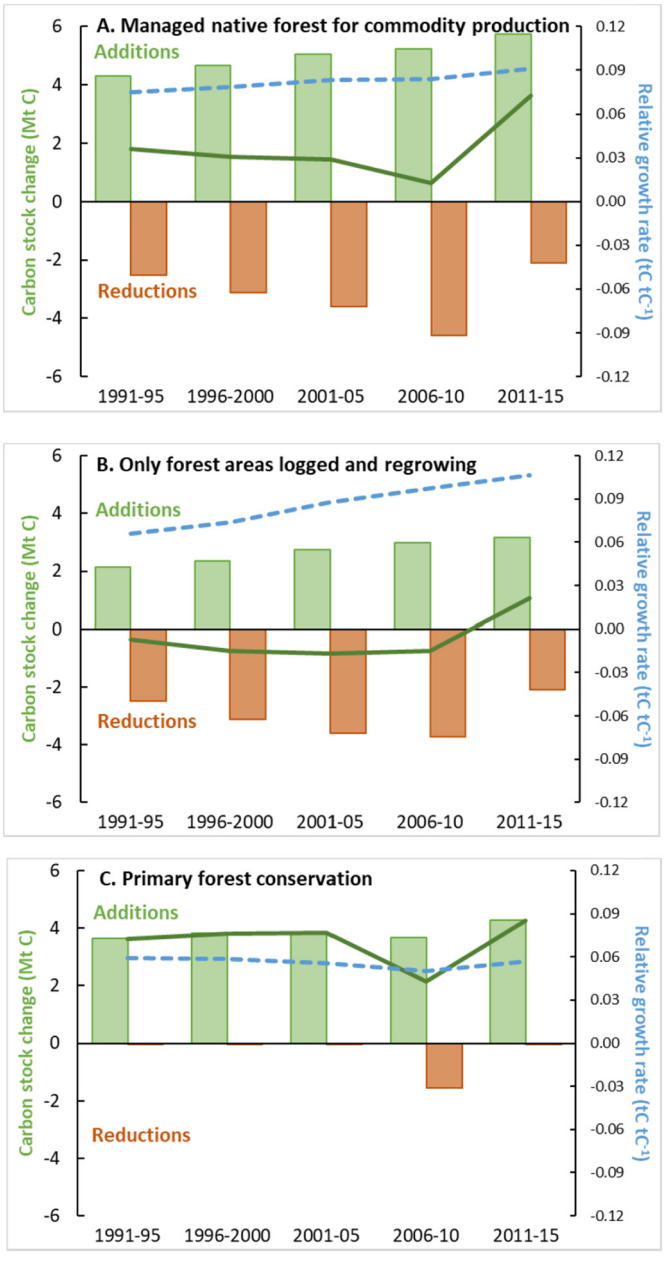

Fig. 5. Carbon stock change assessed for forest areas in the Central Highlands region of south-eastern Australia. A. Secondary native forest managed for commodity production (includes area of forest logged and regrowing plus areas that are available for logging); B. subset of secondary native forest that includes only the area logged and regrowing; C. primary forest managed for conservation. Carbon stock change in each 5-year time period is shown as gross flows of additions and reductions (green and orange bars, respectively), and net change (dark green line). Relative growth rate is shown as a blue dotted line on the secondary Y axis. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Quantifying land sector carbon has the highest uncertainty in IPCC accounting (Friedlingstein et al., 2014), yet countries are expecting substantial mitigation contributions from land-use, especially forests, in their NDCs (Grassi et al., 2017; Rockström et al., 2017). Reducing uncertainty in estimation and improving transparency in reporting are key objectives for accounting systems to inform trade-offs in land-use activities, quantify mitigation outcomes and track towards global targets under international conventions.

A comprehensive accounting system, which links carbon stocks and flows with other ecosystem assets and services and benefits to humans, will facilitate consistency in policy development for the UNFCCC Paris Agreement along with other international conventions and processes. The IPCC 6th Assessment Report Working Group III on mitigation and the Sustainable Development Goals are giving far greater consideration to the role of nature-based solutions, with the review of Goal 15 Life on Land noting the importance of developing metrics for differentiating the 'quality' (or condition) of ecosystems not merely recording extent (UN, 2019). Negotiations for the Convention on Biological Diversity post-2020 targets have recognised the links between biodiversity and GHG mitigation in the land sector. The UN SEEA EEA revision process aims to achieve a statistical standard by early 2021. Developing synergies, identifying interdependencies, and coordinating activities in the development of rules, protocols and targets, will strengthen all international conventions.

5.3. Limitations and further research

Design of the carbon accounting system with the ten essential components encompasses understanding of ecosystems and their role in the carbon cycle and represents the theoretical framework. Challenges exist in implementation with the practicalities of populating the accounts with data. Availability and quality of data sources will be limited. Current challenges include measuring total carbon stocks and stock changes in all components in the biosphere and accumulation in the economy, differentiating qualities of carbon stocks, and identifying proportions of carbon stocks in reservoirs at risk of loss. There will also be issues related to boundaries of carbon stocks measured, for example, depth of soil or dissolved organic carbon in groundwater. However, a framework that is comprehensive, with all stocks in scope, provides the capacity to include all stocks when data are available, rather than enforcing a priori global decisions in the accounting guidelines. An example of combining data sources of differing qualities to develop a comprehensive account is presented by Ajani and Comisari (2014). Determining a reference level from which to assess changes in carbon stocks can be problematic, especially in highly modified ecosystems (methods and examples described in Keith et al., 2020). A key advantage of accounting is that it forces the reconciliation of data from different data sources and over time the data and methodologies improve (Vardon et al., 2018).

This accounting system refers to the recording of carbon stocks and flows in physical terms, with data that populate a carbon stock account and physical supply and use accounts for ecosystem services. A separate stage involves translating these physical metrics into monetary metrics related to transactions of ecosystem services. In determining monetary valuations, it is important that accounting principles are maintained by ensuring stocks and stock changes are not double counted. Valuation methods involving stocks of carbon require further research to derive statistically rigorous approaches that also provide appropriate policy signals for the ecosystem service of global climate regulation.

CRediT authorship contribution statement

Heather Keith: Conceptualization, Methodology, Validation, Formal analysis, Visualization, Writing – original draft, Writing – review &

Table 5
Additional components to create comprehensive carbon accounts, the new information revealed and the potential for missing information.

Information revealed by comprehensive accounting	Missing information from current accounting	Case study example
1. All land included in spatial areas of ecosystem accounts Managed (or production) forest and unmanaged (conservation) forest are included. ⇒Comprehensive spatial area	Some lands are excluded. Degree of management of land is difficult to distinguish. ⇒ Missing land areas, confusion over definitions	More than half the carbon stock in the case study region is stored in conservation forests.
2. All carbon pools All carbon pools are recorded, even if estimated. ⇒ Comprehensive carbon stocks	Total change in carbon stocks may not be recognised if all pools are not measured. ⇒ Missing carbon stocks	Aboveground biomass is often reported, but 20% of tree biomass can be belowground, and 10–30% of total biomass is dead as standing trees, logs and litter.
3. Quality of carbon stocks Forest types distinguished as natural, production and plantation, which determine quality of the reservoir. ⇒ Risk of carbon loss can be assessed	Carbon stocks in all forests are counted equivalent. ⇒ True mitigation value cannot be assessed.	Carbon stocks in dense, even-aged regrowth forests and plantations have a greater risk of damage and carbon stock loss due to wildfire, pests and drought.
4. Definition of forest Carbon stocks and stock changes recorded for all land cover classes at the current time. ⇒ Actual changes are recorded	If a land cover class can be actual or potential, then changes may not be recorded. ⇒ Missing changes in carbon stocks	Logged areas that do not regenerate are not counted as a loss in forest cover, and so the loss of carbon stock is not recorded.
5. Biosphere and atmosphere The biosphere and atmosphere recorded as separate environment units. ⇒ Transfers are transparent	All transfers to the atmosphere may not be recorded. ⇒ Total increase in atmospheric carbon stock underestimated	Emissions from activities in the biosphere are recorded as used by the atmosphere.
6. Reference level of the natural state Carbon stock change is calculated from the original condition of the ecosystem, or estimated as possible. ⇒ Defines carbon carrying capacity	Change since business-as-usual or mature forest at end of rotation does not account for initial stock loss. ⇒ Full carbon sequestration potential not realised	Old growth forest has at least 30% higher carbon stock than a mature production forest.
7. Measuring and recording gross flows Gross flows recorded as removals due to growth, emissions due to fire, and emissions due to logging ⇒ Shows absolute gains and losses	Net flows recorded Net ecosystem carbon balance measured ⇒ Hides differences due to forest management	Higher rate of sequestration in conservation forest (2.42 tC ha^{-1} year^{-1}) than production forest (-0.56 tC ha^{-1} year^{-1}).
8. Ecosystem condition Long-term average carbon stock is the metric assessed under different forest management regimes. ⇒ Shows difference in stock between biosphere and atmosphere	Sequestration in terms of annual biomass increment is used as the metric. ⇒ Longevity of the carbon stock is not accounted	Long-term carbon storage in conservation forests is twice that stored in production forests, and hence has a greater mitigation benefit.
9. Carbon storage as an ecosystem service Carbon storage supplied by forests in the environment Use by government in the economy for collective good. ⇒ Shows mitigation benefit	If carbon storage is not supplied by the environment, then stock loss would be used by the atmosphere. ⇒ Hides risk of climate degradation	Loss of carbon stock in Central Highlands forest (147 Mt. C) is equivalent to Australia's total emissions for 1 year.
10. Opportunity cost if all forest continued growing. Carbon sequestration potential is calculated as the difference between the current carbon stock and the carbon carrying capacity. ⇒ Shows the opportunity cost of protecting forests	Carbon sequestration potential cannot be calculated fully without a reference level of the natural state. ⇒ Sequestration potential not recognised	Continued regrowth of logged forests has a carbon sequestration potential of 3 tC ha^{-1} year^{-1}.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. List of abbreviations

CBD	Convention on Biological Diversity
CO_2	carbon dioxide
GHG	greenhouse gas
IPCC	International Panel on Climate Change
NDC	Nationally Determined Contributions
NbS	nature-based solutions
SDG	Sustainable Development Goals
SEEA EEA	System of Environmental-Economic Accounting Experimental Ecosystem Accounting
UNFCCC	United Nations Framework Convention on Climate Change

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January 22, 2024

Melissa Hoffer, Climate Chief
Office of Climate Innovation and Resilience
Executive Office of Energy and Environmental Affairs
100 Cambridge Street, 10th Floor
Boston, MA 02114

Dear Chief Hoffer,

The Massachusetts State Chapter of the National Wild Turkey Federation (NWTF-MA) appreciates the opportunity to provide comments on the recently released Report of the Climate Forestry Committee (CFC): Recommendations for Climate-Oriented Forest Management Guidelines. We greatly appreciate the time and effort spent by the CFC in developing these recommendations.

We support many of the recommendations and believe their implementation will yield tremendous benefits for the Commonwealth by leveraging the ability of our forests to sequester and store carbon. However, we encourage further consideration of the tradeoffs impacting wildlife and biodiversity when pursuing passive and active management strategies to prioritize carbon benefits. We offer the following comments relative to the recommendations and suggestions put forth in the report:

- We urge caution with the CFC's recommendation that MassWildlife should reassess and reduce current habitat goals for grasslands (1-2%), shrublands (8-9%), and young forest (10-15%), in favor of more emphasis on late successional habitat and development of old growth characteristics. Ninety-nine Species of Greatest Conservation Need identified in MA's State Wildlife Action Plan require the important habitat types identified above.

- We believe that increasing the pace and scale of early successional habitat management will be the most efficient and effective way to meet MA's early successional habitat (ESH) needs, rather than some combination of natural ecological disturbance and maintaining existing ESH habitats as suggested. Land managers need to apply active management on the landscape where it is needed by wildlife to create a connected mosaic of habitats that will allow these species to persist and facilitate adaptation to an uncertain climate future.

- We reiterate our support for providing locally sourced wood products. Local wood products supply only an estimated 6% of MA's annual wood consumption needs. More investment could be made in sustainably harvesting wood products in MA, where the best silvicultural practices can be used to achieve multiple benefits.

- Similarly, we support a combination of active and passive management strategies on DCR Division of Water Supply Protection watershed forests. The application of active management in these watersheds can accelerate the development of

structural complexity and forest resiliency needed to protect water filtration functions, while addressing other objectives related to wildlife habitat and wood production.

Most importantly, as the Executive Office of Energy and Environmental Affairs (EEA) works with MassWildlife and the Department of Conservation and Recreation to begin implementing these recommendations and guidelines, we advocate for the CFC's recommendation, *"Flexibility is needed and agencies must be empowered to make considered decisions, informed by public input, that involve tradeoffs and simultaneously seek to achieve multiple goals.*"

Again, we greatly appreciate the work and expertise of the Climate Forest Committee in producing this report. We look forward to working with EEA, MassWildlife and DCR to help enhance forest health, resilience, and the ability to meet the diverse needs of the Commonwealth.

Yours in Conservation,

Chuck DuPont

Chuck DuPont
NWTF State Chapter President, Massachusetts

MASSACHUSETTS FOREST ALLIANCE

249 Lakeside Avenue, Marlborough Massachusetts 01752-4503
www.MassForestAlliance.org | (617) 455 - 9918 | info@MassForestAlliance.org

January 24, 2024

Stephanie Cooper, Undersecretary for Environment
Executive Office of Energy and Environmental Affairs
100 Cambridge St, 10th Floor
Boston, MA 02114

Undersecretary Cooper:

Thank you for the opportunity to comment on the report of the Climate Forestry Committee (CFC). In general, we have mixed feelings about this report, and feel that there were some avoidable errors that made the report less useful than it could have been and more confusing than it needed to be.

Moratorium

Before we get into comments on the report itself, an aside about the associated moratorium on forest management work on state lands. As you know, we felt the moratorium was entirely unnecessary and unjustified. It has lasted more than a year now, since the approved 2022 DCR forest management projects were pulled back with no explanation in December 2022. EEA's attempt to call it a six- or seven-month moratorium by excluding early 2023 when it allowed projects with approved and already-signed contracts with timber harvesters to proceed is misleading at best, as EEA would have been in breach of contract had it tried to stop those projects.

At the beginning of the CFC process, we told EEA that our top priority was getting the previously approved 2022 DCR forest management projects out to bid as soon as the moratorium was lifted. We suggested having the CFC use the projects as real-world case studies, altering them if necessary, and then releasing them to bid immediately after the CFC report was issued. We were told this was a very smart idea and you would try to make it happen. Instead (despite the wishes of a number of members of the CFC), those projects are now being reviewed anew and delayed further. As a result, the moratorium will continue in effect until projects are once again put out to bid, which could be months away. We hope you will reconsider this decision, or at least significantly speed up the review.

These decisions have a real effect on small businesses that are a key part of the economy in struggling rural Massachusetts. For some timber harvesters, work on state lands was 30% of their business. To lose that for more than a year (some had outstanding contracts they finished early in 2023) has had a major effect on their livelihoods. They were hurt further by very wet weather in 2023, which made timber harvesting impossible for long stretches of the year.

This resulted in a ripple effect on other businesses. Massachusetts sawmills could not get enough wood supply and had to reduce their hours – in some cases, going down to operating only one day a week. We worked to connect mills in various

parts of Massachusetts with timber harvesters and mills in other parts to help minimize the damage as much as possible, but it proved impossible to mitigate it much. Even larger mills in northern New England that purchase Massachusetts-grown wood struggled. While farmers who were seriously hurt by flooding in 2023 were showered with state aid, no effort was made to help forest-related businesses, who were also seriously impacted.

Regulators and policymakers need to understand that their decisions related to the moratorium really hurt these family-owned small businesses, and some may not recover. In recent years we have seen some of our members retire earlier than planned (worsening a workforce crisis) and others move to the southeastern United States for better opportunities. There is a real-world impact of policies and regulations that is too often entirely overlooked by people on Beacon Hill. We urge you to move with all deliberate speed to restart forest management on state lands to avoid further economic damage.

CFC Structure and Membership

Turning our attention to the CFC report, our first concern was with the composition of the CFC. We felt that EEA made some odd choices in designating this panel. We pointed out that there were few or zero members who actually managed forestland directly. EEA responded to this criticism by designating on its website those members of the CFC who were licensed foresters. However, few of these people were active consulting foresters, and were instead academics or worked for nonprofits.

We thought not having a single timber harvester on the panel was a mistake as well. With few people actively managing forestland, there was a risk that real-world impacts would be entirely overlooked. For example, we've seen with the Family Forest Carbon Program that timber harvests permitted under the program are right on the razor's edge of profitability for timber harvesters, requiring them to be extremely careful how (and if) they bid on these projects. We were concerned that something similar could happen with this effort. We were assured that harvesters and foresters would be consulted during the process to make sure this didn't happen, but it's unclear if that actually happened or not.

Creating a panel to review nursing staff levels that only included hospital administrators – even if some were doctors or nurses by training and licensure – would be a bad idea. We believe the same is true here. While we have tremendous respect for individual members of the CFC, we think EEA would have been better served by including some people who make their living in the woods.

With strong (even shocking) recommendations related to MassWildlife's wildlife habitat work, it was unfortunate that there was no wildlife biologist on the CFC who could have contributed their knowledge to the group. The report notes that MassWildlife and other agencies made presentations to the CFC. However, having someone with this expertise in the room during deliberations may have better informed decision-making.

EEA selected at least one CFC member adamantly opposed to forest management on state lands in virtually any circumstance. This choice was presumably made to attempt to capture all viewpoints, but EEA was hoping for the CFC to reach consensus on recommendations, and this choice made that all but impossible, even with the help of a professional mediator.

Emphasizing Minority Views

This failure was exacerbated by EEA's curious decision to give equal time and space to dissenting views, even if they were from just a small minority of CFC members. By essentially serving only as meeting minutes with little clarification, the report became less useful, as it must be read very carefully to try to determine where the majority of the CFC came down. Over the course of 70 pages, keeping track of how many people said "X" or "Y" becomes exhausting to the reader. EEA should have instead gone into detail on the majority view and only briefly noted minority views to make the report clearer and easier to understand.

By uncritically reporting all minority statements in the report, EEA also caused confusion. For example, the report correctly states that in Massachusetts, tree mortality massively outweighs removals from harvesting – by a ratio of more than 3 to 1 (p. 20). However, the report later prints a favorite talking point from those opposed to forest management, saying "they note that from a regional perspective, harvesting is the largest total source of emissions from forests relative to other disturbances" (p. 43). While at first glance the two statements seem diametrically opposed, the second statement is technically correct given the modifying language, "from a regional perspective." But the report focuses on Massachusetts forests, and **the second statement is 100% false when applied to Massachusetts forests.** By including a statement that is true only if you include the heavy cutting in northern Maine, EEA caused unnecessary confusion.

Report Content Overview

In general, our view on the report is that it too often appears to the reader as conclusive when in fact there are significant exceptions to many of the statements. These exceptions are at best touched on very briefly, and with far less emphasis than the blanket statements they modify. This tends to cause the reader to misinterpret the report and have a perception that it is largely hostile to forest management, which is what we heard from people that read the report – our members, reporters, staffers at environmental organizations, and others.

Additionally, there is a lack of discussion and a minimizing of factors that could jeopardize the benefits of forest reserves. We're also concerned about strong positions taken on salvage logging and wildlife habitat work that may overstate the case or be misleading, and the report is missing language around the values of timber stand improvement and modern wood heat.

Carbon Sequestration and Storage

There is strong language in the report regarding the carbon benefit of reserves, stressing that in most or nearly all cases, placing forestland in reserves will result in more carbon storage compared to actively managed forest. We're concerned that the report leans too far in this direction and does not do a good job of exploring any number of scenarios where this is not the case.

We join leading environmental organizations in Massachusetts in supporting a mix of reserves and sustainably managed forest on state lands. We believe these reserves need to be properly sited. Forest stands highly vulnerable to disturbance are unlikely to result in more carbon storage, especially long-term. With growing threats from invasive insects and plants, deer browse, severe weather, and other climate change impacts, the security of that carbon storage is in question. For example, Harvard Forest, through careful carbon flux measurements, found

their hemlock stands had become a carbon source – emitting more carbon into the atmosphere than they were sequestering, due to the hemlock woolly adelgid. Some leading forest ecologists suggest that we may be better off trying to manage for resilience rather than manage for carbon for this reason.

As stated above, the CFC report does acknowledge significant mortality in Massachusetts forests. But there is little effort made to explain that this represents a serious threat to carbon stocks in forest reserves, other than brief mentions. In fact, this should be stressed in the report as a major concern and a call for research by the CFC and EEA. While the report does call for the Commonwealth to increase research on forest carbon, many of these suggestions are focused on research of the impact of harvesting and active management rather than the security of carbon storage in reserves. DCR's Continuous Forest Inventory program data should be communicated out to the public in a much broader fashion. It's important to note that this CFI data has indicated that reserves may be falling behind actively managed parcels in carbon storage, contrary to the presentation of the report that reserves are virtually always better for carbon storage. There needed to be much more nuance and thorough explanation here.

As an example, the recent **Managing Forests for Carbon in Massachusetts** publication from DCR, the Northern Institute of Applied Climate Science (NIACS), and Mass Audubon talks about the importance of the right site selection for forest reserves. It points out that sites that are highly vulnerable to disturbance are poor choices for reserves and are better suited for active management. It also explores the statement that reserves are always better than actively managed forest for carbon storage:

> ***Does eliminating harvest provide the biggest carbon benefit?***
> *Among the many messages heard regarding forests as a natural climate solution, one of the most prevalent messages relates to eliminating forest harvest and allowing forests to grow old and maximize their climate mitigation potential. Reducing or eliminating harvesting activities on many sites will increase forest carbon in the near term, however active management provides carbon benefits as well:*
>
> - *Sequestration and storage: the rate of sequestration of additional carbon diminishes as forests mature. Maintaining low- to moderate-levels of disturbance, either through natural or intentional processes, can maintain both high carbon stocks while sustaining high rates of sequestration by creating structurally complex forests.*
> - *Maintaining a healthy forest is important for preventing the release of CO2 back to the atmosphere. Forests vulnerable to climate impacts, disturbance, or forest health issues are at risk of carbon loss. Active management in these situations can reduce risk, improving the longevity of carbon on the land and the ability to sequester additional carbon.*
>
> *Old-growth forests (forests that were never cleared following European settlement) in the Northeast are rare and valued places that are protected for their unique ecological value. It is important to recognize that these systems developed over long periods of time, largely under conditions different from our current climate and the climate of the future. Many of our current forests—even mature forests a century or more old—are recovering from past clearing, agricultural abandonment, and multiple harvests over the past century and a*

half. This legacy often results in very different stand conditions from an old growth forest. These forests are often lacking in species diversity and structural complexity, which combined with climate and other stressors make them more vulnerable to carbon loss.

Assuming all mature and old-growth forests will store additional carbon into the coming decades (or longer) by eliminating harvest is not supported by our current scientific understanding of climate vulnerability, so assessing site vulnerability is critical.

This is an example of the careful consideration, nuance, and thorough exploration of forest carbon and reserves that is missing from the CFC report. The fact that the same executive office is releasing reports with very different apparent takes on forest carbon is confusing.

The CFC report acknowledges that as forests age, their annual carbon sequestration rates fall. But there is no direct statement indicating that we expect that as our forests age, their sequestration rates will continue to decline, reducing the amount of carbon emissions they can offset (never mind the impact of increasing mortality). There is no acknowledgment that **even if we never cut a tree again in Massachusetts, there will not be enough carbon sequestration to offset even the 15% of carbon emissions remaining after we cut all the carbon emissions from every sector that we can**. The chart on page 13 correctly shows a clear decline in carbon sequestration from natural and working lands from 2030 to 2050. There is another colored chunk labeled "Additional Carbon Sequestration" that enables the Commonwealth to reach net zero, but there is no mention that this refers to Massachusetts purchasing carbon credits from heavily forested Maine and is not the result of recommendations in the report, which potentially could result in speedier declines in sequestration rates compared to the status quo. We believe this is critical information that needs to be communicated to the public to increase their knowledge and understanding.

Salvage Logging

As for salvage logging, we believe this is a topic that is far more complex than it might appear. The report states that salvage logging causes carbon losses in the short term, which most readers might interpret as permanent carbon losses that take place in the short term, not a temporary loss that is erased within a decade or two, which is what the study actually says. The study that is cited examines tree species – fir and spruce – not in abundance in Massachusetts, but present in northern New England. It also involves salvaging all the timber, including low-grade trees.

We wonder if an alternate approach – salvaging only the sawtimber and, as much as possible, leaving low-grade trees behind – would lead to entirely different results. It's quite possible that choosing NOT to do this type of salvage logging might actually incur a carbon loss instead of being protective of forest carbon. This is something that should be researched, as we're not aware of this type of salvage being studied.

EEA has said this report's recommendations will be incentivized on privately owned forestland. We're particularly concerned about the application of this section to private lands. Forest landowners simply cannot allow all the timber value on the property to rot and decay after a blowdown – they MUST salvage for economic reasons, or their forestland is vulnerable to being

sold for development. We were glad to see the report acknowledge this and urge EEA to be careful about discouraging salvage on private forestland.

The report seems to take an extremist position – salvage logging is almost always bad – and then gradually backs off from it by listing exceptions. We believe these exceptions are important, and urge EEA to not prohibit these types of salvage – to respond to insect infestations, public safety, access, etc. There is a brief mention of costs, and this is important. It makes far more sense for agencies to salvage timber for public safety through logging where at least some of it can go into long-lived wood products and perhaps earn the agency money rather than wait until it is all dead and then pay tree service companies to come in at huge expense to fell and chip the dead material to protect public safety.

We're somewhat skeptical of the suggestion to avoid salvaging any ash trees in the hope that some might miraculously have a resistance to the Emerald Ash Borer that could be studied. We've heard estimates that one in 10,000 or even 100,000 trees might be considered "lingering ash" but are unaware of any resulting scientific discoveries that could halt the spread of EAB. Instead, it appears that introduced biocontrols might succeed in protecting young ash trees long-term, helping slowly restore the species. Decisions here should be driven by science, not hope. From a carbon perspective, we might be better off turning at least sawtimber-quality ash into furniture, flooring, and baseball bats rather than holding out hope of a miracle. Additionally, ash in its final dying stages becomes extremely brittle and is a serious danger to fall in any sort of windy conditions, representing a public safety threat if located anywhere near roads, trails, campsites, or other recreational areas – opening the agencies to liability claims. We would encourage EEA to think carefully before adopting this recommendation, and perhaps limit it to areas of interior forest where people are unlikely to go.

Access is also important. We have been concerned about DCR's decisions in reserves. The feeling seems to be that reserves should discourage heavy human recreational use, which makes sense. But rather than controlling access, posting signage, or taking other steps to accomplish this goal, DCR has too often chosen a strategy of neglect by allowing access routes to slowly become unusable. This won't stop people from hiking or even biking into the property, but will prevent emergency services crews from reaching victims of a fall, heart attack, or other injury. Again, it may make sense to salvage sawtimber from such access projects while just pushing low-grade wood off trails and roads.

Wildlife Habitat

We are concerned about the strong opposition to wildlife habitat creation in the report. There is language stating that utility corridors, now that herbicide use has apparently dropped, are perfectly suitable to meet the needs of species that need early successional forest habitat. There is substantial scientific evidence that a narrow utility corridor is in fact not ideal for these species. Predators typically lurk at the mature forest's edge nearby, and many species will not nest too close to it. Best practices for early successional forest habitat are to create an opening five acres or more in size to create sufficient distance from the edge.

There is also growing evidence that even mature forest-dwelling bird species tend to forage for food in early successional forest habitats nearby (because early successional habitat is rich in food and biodiversity), and in fact tend to dwell there themselves after fledging their young.

Early successional habitat is important for more than just migratory songbirds – threatened bees and snakes also thrive in it (and a study in Massachusetts shows they do not prefer utility corridors).

There is little discussion of various forest types and how or if that would change recommendations related to wildlife habitat management other than a brief statement on page 47. A number of the studies cited in the report seem to focus on northern hardwood forests, which are largely present only in western Massachusetts. There is no discussion in the report of pine barrens beyond that brief mention on page 47 – a globally rare habitat that is strongly fire-influenced, and which MassWildlife has been restoring and maintaining with prescribed fire with great success, with groups of wildlife biologists coming from across the country to learn more.

The CFC report appears to ask MassWildlife to lower targets it set in the State Wildlife Action Plan (SWAP) for early successional habitat. We're not sure how calling for an end to achieving the goals in the SWAP squares with the Governor's executive order on biodiversity. It's equally difficult for us to understand how the CFC would recommend essentially violating the Massachusetts Endangered Species Act (MESA) as a policy to be implemented by EEA. We would encourage EEA to take a closer look at the suitability of utility corridors and not rely on a single study or handful of studies when we believe the science is much more unsettled on this point.

Timber Stand Improvement

There is a mention of understocked private forestland on page 50, but no mention at all of overstocked private forestland. This is odd because the vast majority of private forestland in Massachusetts is overstocked. The carbon benefits of thinning an overstocked stand are proven by science. In fact, the Family Forest Carbon Program chose it as one of two practices based on extensive research. The science was clear that it can lead to carbon benefits in even the very short term – 20 years.

EEA has made it clear – and it is reflected in the CFC report as well – that producing more long-lived durable wood products is a key goal for actively managed forestland in Massachusetts. This is a challenge because much of our forestland is overstocked with low-grade wood that, no matter how many years it grows, cannot ever become high-quality sawtimber. The only way to encourage the growth of more sawtimber is to engage in what's called Timber Stand Improvement (TSI). This involves thinning the forest to remove poor-quality trees and concentrate growth in high-quality trees that can become long-lived durable wood products, while also allowing more light to reach the understory, where the best, most vigorous, and most suitable trees for future sawtimber can be favored.

The issue is that TSI costs a landowner money to implement, because it removes only low-grade trees with little market value. There is some funding available from NRCS, but it can be difficult to work through the complicated process. The New England Forestry Foundation recently received a $30 million grant from the USDA's Climate Smart Commodities program to produce more wood while increasing carbon benefits. A large chunk of the program will incentivize large forest landowners in northern Maine to let their understocked forests come up to full stocking. But a portion will be spent in Massachusetts and southern New England to

help landowners thin their overstocked stands in a TSI effort that will reduce mortality rates and increase the supply of sawtimber while having carbon benefits as well.

It's astounding to us that TSI and thinning overstocked stands received no mention whatsoever in the report. The only mention of thinning is to encourage the removal of *fewer* trees overall, which does nothing to produce future sawtimber and durable wood products. We think this is a serious error.

There are tradeoffs between managing only for carbon and managing for a variety of ecosystem services and wood production, which the report correctly indicates. But to simply ignore such a key part of producing low-carbon wood products in a report dedicated to climate-oriented forest management is bizarre. We encourage EEA to closely examine this issue as it looks for ways to implement the recommendations in the report.

Modern Wood Heat

There is no mention in the report of modern wood heat. While the CFC had no one with any knowledge or experience with this issue on the CFC, it nevertheless can be an important part of climate-oriented forest management. The carbon emission reductions found by switching from oil heat to modern wood heat are proven beyond all doubt – particularly when using residues from timber harvesting and from sawmills. That wood is destined to release its carbon in a short time frame, so the carbon emissions reduction impact is even greater.

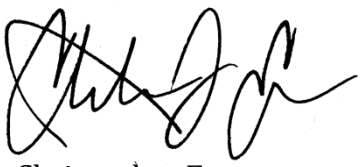
Given that the CFC knew little about this topic, it's not surprising that it wasn't included. But we believe that EEA should be thinking about this as it moves forward with implementation.

Summary

The CFC was asked to create a meaningful report on a very short deadline, which was a major challenge. We thank the CFC members for their efforts. However, we believe that EEA's choices with the membership of the CFC, the methodology for their work, and the design and structure of their report led to a final work product that can be confusing and potentially lead the average reader into making false assumptions about forest carbon and forest management. The fact that this effort was tied to an unnecessary and lengthy moratorium that seriously hurt our members makes the final result even more disappointing.

Thank you for the opportunity to comment.

Sincerely,



Christopher Egan
Executive Director

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MARK BRINSON REVIEW

Wetlands In a Changing Climate: Science, Policy and Management

William R. Moomaw[1] · G. L. Chmura[2] · Gillian T. Davies[3] · C. M. Finlayson[4] · B. A. Middleton[5] · Susan M. Natali[6] · J. E. Perry[7] · N. Roulet[2] · Ariana E. Sutton-Grier[8]

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Abstract

Part 1 of this review synthesizes recent research on status and climate vulnerability of freshwater and saltwater wetlands, and their contribution to addressing climate change (carbon cycle, adaptation, resilience). Peatlands and vegetated coastal wetlands are among the most carbon rich sinks on the planet sequestering approximately as much carbon as do global forest ecosystems. Estimates of the consequences of rising temperature on current wetland carbon storage and future carbon sequestration potential are summarized. We also demonstrate the need to prevent drying of wetlands and thawing of permafrost by disturbances and rising temperatures to protect wetland carbon stores and climate adaptation/resiliency ecosystem services. Preventing further wetland loss is found to be important in limiting future emissions to meet climate goals, but is seldom considered. In Part 2, the paper explores the policy and management realm from international to national, subnational and local levels to identify strategies and policies reflecting an integrated understanding of both wetland and climate change science. Specific recommendations are made to capture synergies between wetlands and carbon cycle management, adaptation and resiliency to further enable researchers, policy makers and practitioners to protect wetland carbon and climate adaptation/resiliency ecosystem services.

Keywords Carbon in wetlands · Global Carbon cycle · Carbon sink and sources · Inland wetlands carbon · Coastal wetland carbon · Peatland carbon · Permafrost · Climate resiliency · Climate adaptation · Wetlands and climate policy · Coastal wetlands · Northern peatlands · Climate impacts on wetlands · Greenhouse gasses and wetlands · Wetland soils · Wetland restoration · Wetland conservation · Wetland protection · Climate change

✉ William R. Moomaw
william.moomaw@tufts.edu

G. L. Chmura
gail.chmura@mcgill.ca

Gillian T. Davies
gdavies@bscgroup.com

C. M. Finlayson
mfinlayson@csu.edu.au

B. A. Middleton
middletonb@usgs.gov

Susan M. Natali
snatali@whrc.org

J. E. Perry
jperry@vims.edu

N. Roulet
nigel.roulet@mcgill.ca

Ariana E. Sutton-Grier
ariana.suttongrier@gmail.com

[1] Center for International Environment and Resource Policy. The Fletcher School of Law and Diplomacy and Global Development and Environment Institute, Tufts University, Medford, MA 02155, USA

[2] Department of Geography, McGill University, 805 Sherbrooke St W, Montreal, QC H3A 0B9, Canada

[3] BSC Group, Inc., 33 Waldo Street, Worcester, MA 01608, USA

[4] Institute for Land, Water, and Society, Charles Sturt University, Albury, NSW 2640, Australia

[5] U.S. Geological Survey, Wetlands and Aquatic Research Center, Lafayette, LA 70506, USA

[6] Woods Hole Research Center, Falmouth, MA 02540, USA

[7] Virginia Institute of Marine Science, College of William and Mary, PO Box 1346, Gloucester point, VA 23062, USA

[8] Earth System Science Interdisciplinary Center, University of Maryland USA and the MD/DC Chapter of the Nature Conservancy, Bethesda, MD, USA

Introduction

The Millennium Ecosystem Assessment (2005) identifies climate regulation as one of the most significant ecosystem services provided by wetlands, and also identifies their role in buffering the effects of climate change (thereby supporting climate adaptation and resiliency), as well as many additional ecosystem services. Wetlands sequester some of the largest stores of carbon on the planet, but when disturbed or warmed, they release the three major heat-trapping greenhouse gases (GHGs), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Rising planetary temperatures are causing a positive feedback from warming wetlands and thawing permafrost that is accelerating global warming. By 2015 increased concentrations of greenhouse gases in the atmosphere have raised the global average temperature by approximately 1°C above preindustrial values (Hawkins et al. 2017). Further warming is expected to add 130-160 Pg (1 Petagram is 10^{15} grams) of permafrost carbon (C) to the atmosphere by 2100 (Schuur et al. 2015). To place this in perspective, that amount of C is comparable to continuing current annual United States fossil fuel emissions until the end of the century (Friedlingstein et al. 2014, USEPA 2017).

Protecting all types of wetland ecosystems from direct human disturbance, minimizing additional warming by reducing GHG emissions from all sources, and increasing terrestrial CO_2 sinks to remove atmospheric CO_2 are major priorities for limiting future temperature increases.

In Part 1 of this paper, we provide a comprehensive review of the consequences of climate change for saltwater and freshwater wetlands. Freshwater wetlands include a variety of cover types characterized by herbaceous plants, shrubs and/or trees. Some freshwater wetlands are underlain by permafrost (soil temperature <0°C for two or more years). In this paper, saltwater wetlands refer to tidal coastal wetlands that include salt marshes, mangroves and seagrass meadows. We also examine the important and often-neglected role that wetlands play in actively removing CO_2 from the atmosphere and sequestering C in wetland soils over long time periods, the potential for expanding that role and the important climate adaptation and resiliency ecosystem services that wetlands provide. For the purposes of this paper, resiliency is defined as the ability for an ecosystem to restore healthy ecological function, complexity, diversity and processes following a disruption, although specific species and species assemblages may change.

In Part 2 of this paper, we identify international, national, sub-national and local wetlands policies and explain their implications for addressing climate change. We note that often the role of wetlands in climate treaties and policies is only by inference. We conclude by describing how climate scientists, wetland scientists, policy makers and wetland practitioners can manage and conserve wetlands in light of climate change.

Part 1: Wetlands In a Changing Climate: The Science

The United Nations Framework Convention on Climate Change calls for the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (UNFCCC 1992). The Paris Climate Agreement in 2015 (UNFCCC 2017) established a goal of keeping global average temperature increase substantially less than 2°C above the preindustrial value, and making every attempt to keep it below 1.5°C.

In order to have a two in three probability of keeping global average temperature from rising by more than 2°C, it is essential to have "negative emissions" of GHGs; in other words, meeting the goal of the Paris Climate Agreement requires active removal and sequestration of atmospheric C (Sanderson et al. 2016). Sequestration is used here to refer to the photosynthetic removal of CO_2 from the atmosphere and its conversion into cellulose and other carbon compounds in plants, and its conversion from decaying plants into soil organic matter. Ricke and Caldeira (2014) have shown that peak warming occurs within about one decade after a pulse of CO_2 is added to the atmosphere. Hence the benefits of avoided CO_2 emissions will be manifested within the lifetimes of people who acted to avoid those emissions. Solomon et al. (2009) have shown that after peak warming is reached, effects will persist for 1000 years. IPCC estimates that depending upon the scenario, "about 15 to 40% of CO_2 emitted by 2100 will remain in the atmosphere longer than 1000 years" (Ciais et al. 2013) affecting 40 generations. Hence avoiding emissions of GHGs to the atmosphere is recommended to be a prime consideration that benefits both present and future generations.

For most types of wetlands, the bulk of sequestered carbon is in the soils rather than in the plant communities. Draining these wetlands to convert them to agriculture as has been done in many countries and regions including Indonesia, Malaysia, Russia, New Zealand, Florida Everglades and in Northern Europe, allows soil organic matter to be oxidized and release CO_2 into the atmosphere. When mangroves are removed for coastal development and for aquaculture, or forested wetlands are harvested, additional carbon is released from soils and harvest residues. In the Southeast United States, a major wood pellet fuel industry has developed where the carbon in the wood is released as CO_2 immediately upon combustion. The use of wood pellets to replace coal for electricity, on the mistaken assumption that it is carbon neutral, is expected to grow substantially by 2050 (IEA 2017), further degrading forested wetlands while adding large amounts of CO_2 to the atmosphere.

CO_2, added to the atmosphere by human activity, is the primary GHG responsible for climate change, followed by CH_4 and N_2O (Myhre et al 2014). These gases move among

the natural reservoirs of terrestrial and marine plants, soils, oceans and the atmosphere. Human activity has reduced the size and capacity of these reservoirs while increasing GHG emissions (Ciais et al. 2013). Altering albedo (solar reflectivity from the earth's surfaces) from land use change can increase or decrease global warming. Climate forcing (heat trapping) from black C (particulate matter from fossil fuel and biofuels combustion (Bond et al. 2013) is a significant contributor to global warming.

The average annual anthropogenic CO_2 emissions for the period 2006-2015 are estimated to be 10.3 $PgCy^{-1}$ (Petagrams C per year or 10^{15} grams C per year) with 9.3 ±0.5 $PgCy^{-1}$ from fossil fuels and industrial processes and 1.0±0.5 $PgCy^{-1}$ from land use change (Fig. 1, Le Quéré et al. 2016). The total CO_2 emissions from fossil fuels and industrial processes between 1750 and 2011 are estimated to be 375±30 PgC, and the total amount from land use change is estimated to be 180±80 PgC. Therefore, nearly one-third of CO_2 added to the atmosphere from human activity has come from deforestation and oxidation of disturbed soil organic matter (Ciais et al. 2013). By November 2017, CO_2 in the atmosphere had increased to 865 PgC or 406 ppm (NOAA 2018).

The net annual increase of CO_2 in the atmosphere each year is 4.5±0.5 $PgCy^{-1}$ or slightly less than half of annual emissions, and concentrations have increased by over 40% above preindustrial levels. The biosphere has been the major means for removing and sequestering atmospheric CO_2 for over 300 million years, but its potential to be a major resource for addressing climate change has been underappreciated in current policy discussions. Each year, 2.6±0.5 PgC equal to about 25% of annual emissions is removed by the ocean's phytoplankton or is dissolved in the ocean's waters. The difference between total emissions to the atmosphere and net removals by the oceans requires that an additional amount of CO_2 equivalent to 3.1±0.9 $PgCy^{-1}$ would need to be removed by terrestrial ecosystems to balance the carbon flows. This is nearly 30% of annual anthropogenic emissions from all sources. This analysis only reports estimates of the aggregate removal of CO_2 by the terrestrial biosphere (all plants and soils), and does not explicitly consider the specific role of wetlands as either a source or a sink (Fig. 1, Le Quéré et al. 2016).

CH_4 has a 100-year Global Warming Potential more than 28 times that of CO_2 (Myhre et al. 2013). It is estimated that between 1750 and 2011 human activity has increased

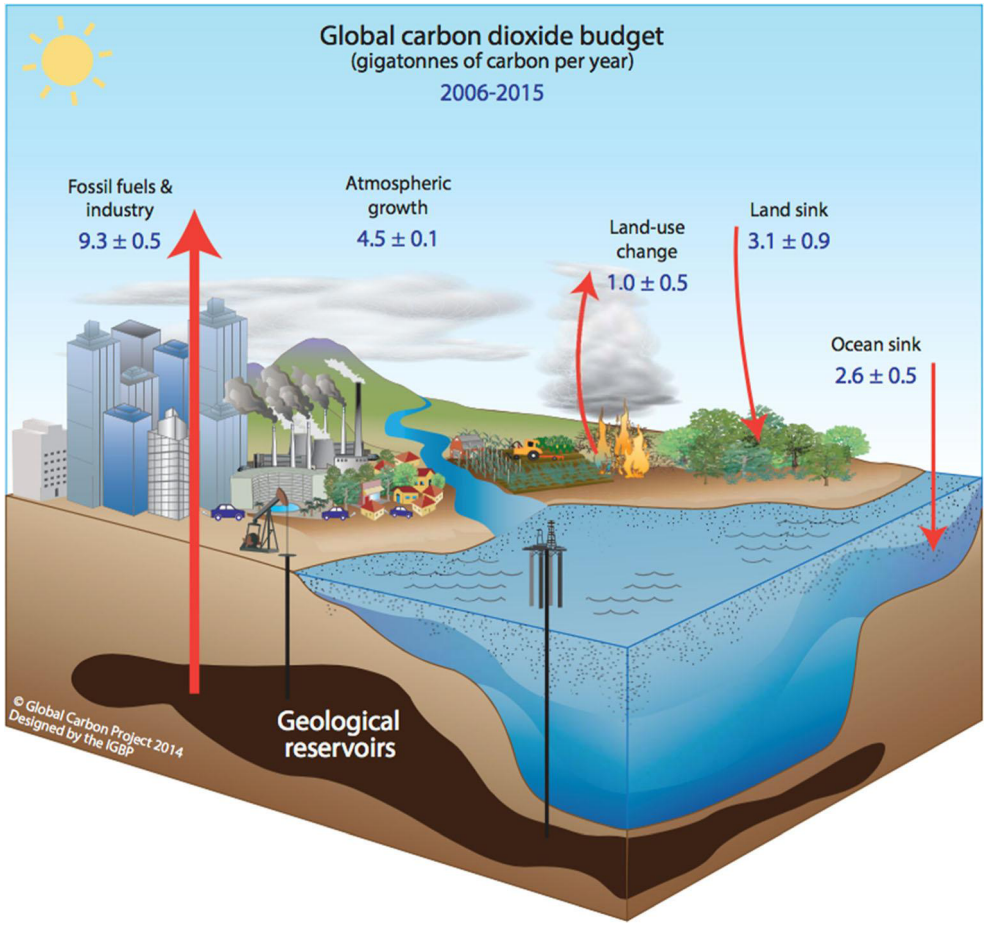

Fig. 1 Global carbon dioxide budget (Le Quéré et al. 2016). Note that approximately 10% of annual emissions are from land use change, and that the land sink removes an amount equal to about 33% of annual emissions. This value is calculated by difference, and wetlands are not counted separately from the total land sink. 1 Gigatonne (10^9 tonnes) equals 1 Petagram (10^{15}) grams

atmospheric CH_4 by a factor of 2.5 from 1984 to 4954 Tg CH_4 y^{-1} (722 ppb to1803 ppb) (1 Teragram CH_4 is 10^{12} grams CH_4) (Ciais et al. 2013). Currently the major sources of emissions arise from fossil fuel usage (85-105 Tg CH_4 y^{-1}), ruminant livestock (87-94 Tg CH_4 y^{-1}), landfills and waste (67-90 Tg CH_4 y^{-1}), and rice production (33-40 Tg CH_4 y^{-1}). Average annual anthropogenic emissions of CH_4 from all these sources between 2000 and 2009 total between 272-329 Tg CH_4 y^{-1} CH_4 is removed from the atmosphere at a rate of 492-785 Tg CH_4 y^{-1} mostly by atmospheric chemistry with small contributions from soil oxidation (Fig. 2) (Ciais et al. 2013). CH_4 emissions from wetlands are between 177 and 284 Tg CH_4 y^{-1}, with an additional 8-73 Tg CH_4 y^{-1} emitted from freshwater sources.

Nitrous oxide (N_2O) has a radiative forcing ~300 times that of CO_2. It is a byproduct of both nitrification (under aerobic conditions) and denitrification (under anaerobic conditions), and thus can be produced in wetland soils (Megonigal et al. 2004). However, freshwater and saltwater wetland soils are a source of N_2O only if they receive excessive levels of reactive nitrogen – otherwise they may be a sink for this potent GHG (e.g. Auget et al 2014, Chmura et al. 2016).

While natural solutions have focused on the role of forests to remove and sequester CO_2, there is substantially more C sequestered in soils than in vegetation. The range of estimates for carbon sequestered in vegetation is 450-650 PgC, while the estimate for C stored in soils is 1500-2400 PgC with an additional 1700 PgC estimated to be in permafrost (Ciais et al. 2013). The large amount of carbon sequestered in wetlands is discussed in subsequent sections. As soils warm, and as permafrost thaws, these soils release their stored C as CO_2 or CH_4 resulting from microbial decomposition of soil organic carbon (SOC). These feedback emissions trap additional heat and warm the planet further. A first priority is to avoid disturbing wetlands and keep temperatures from rising as much as possible. As the subsequent sections illustrate, wetlands can play a significant role in addressing climate change by sequestering C, and by providing climate resiliency and adaptation while providing additional ecosystem services.

To limit excessive warming, it is necessary to stabilize CO_2, CH_4, N_2O and other GHG concentrations in the atmosphere at an appropriate level, by decreasing emission rates and increasing removal rates. There are three basic strategies for accomplishing this goal.

1. Reduce the addition of GHGs into the atmosphere from fossil fuels, biofuels, industry, agriculture and other sources to near zero.
2. Prevent the climate and land-use mediated release of additional GHGs (CO_2, CH_4, N_2O) from wetlands, including wetlands underlain by permafrost, from deforestation

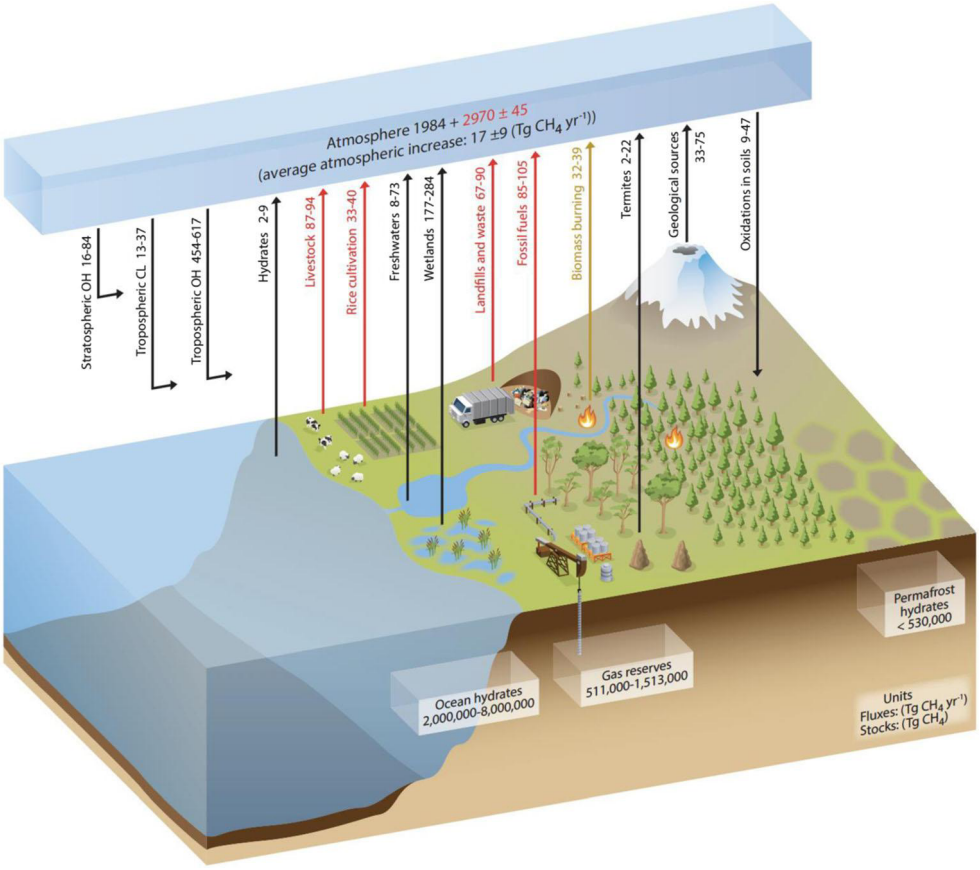

Fig. 2 Global methane (CH_4) budget (Ciais et al. 2013). Average annual anthropogenic emissions of methane from fossil fuels, ruminants, landfills and waste and rice cultivation between 2000 and 2009 total between 272-329 Tgy^{-1}. For comparison, natural wetlands and freshwaters are estimated to release between 185-357 Tgy^{-1}. CH_4 is removed at a rate of 492-785 Tgy^{-1} mostly by atmospheric chemistry with small contributions by soil oxidation. Black arrows represent natural emissions, red arrows represent anthropogenic emissions since 1750, and the brown arrow represents emissions from both natural fires and anthropogenic biomass burning. 1 Teragram equals 10^{12} grams

and forest degradation, and from all soils including degraded grassland and agricultural soils.
3. Increase the capacity of natural systems including wetlands to actively remove CO_2 from the atmosphere and sequester the C for the long-term.

Carbon Accumulation and GHG Emissions from Freshwater Wetlands (Including Permafrost) In a Changing Climate

Wetland conservation has important implications for atmospheric C cycles, since a substantial portion of the soil C pool is stored in wetlands. Northern high latitude and tropical peatlands store more than 600 PgC (Gorham 1991; Hugelius et al. 2014), which is among the largest reserves in the world (Köchy et al. 2015). This amount is more than two-thirds as much as is stored in the atmosphere and comparable to the amount stored in global forest biomass (Pan et al. 2011). Wetland conditions are critical for C accumulation and storage since decomposition in these systems is limited by a lack of oxygen due to water saturation (Brinson et al. 1981). Therefore, when plant productivity exceeds decomposition there is a net accumulation of soil C. This process eventually develops deep peat deposits, which may accumulate for thousands of years. In high latitudes of the Northern Hemisphere, the accumulation process is further intensified by the presence of permafrost, which can have contrasting effects on hydrology, leading to either wetland formation or loss (Sannel and Kuhry 2008). The negative climate feedback (i.e. net cooling effect) that results from increased plant productivity and the long-term C accumulation and storage by wetlands is, in part, offset by CH_4 emissions from freshwater wetlands (Turetsky et al. 2014). Freshwater wetlands represent the largest natural source of CH_4, releasing approximately 180 – 220 Pg CH_4 yr^{-1} (Mikaloff Fletcher et al. 2004, Kirschke et al. 2013). However, wetlands that accumulate peat account for less than a quarter of all wetland CH_4 emissions (Turetsky et al. 2014 and references therein).

The influence of future climate on wetland soils C will depend upon the same factors that facilitated C accumulation in these systems: water saturated soils and minimal modification of wetlands through land-use change, and in the case of high latitude peatlands, low temperature. Globally, temperature, low oxygen (due to soil saturation), and the chemical and physical form of the organic matter, are the primary factors limiting decomposition in wetlands. Changes in precipitation and evapotranspiration patterns, which alter the water balance of wetland ecosystems, will substantially influence wetland C cycling. However, the magnitude, directionality, and seasonality of projected hydrologic changes are regionally variable (Collins et al. 2013), and therefore, the fate of soil C stored in wetlands will depend on local conditions. In contrast, changes in the global energy balance, usually manifested by an increase in temperature, are most likely to accelerate the decomposition rate of wetland organic C stored at the soil surface. Deeper C pools may be unaffected unless there are associated changes in hydrology (van Groenigen et al 2016). These potential losses of belowground C may also be partially offset by increased primary productivity.

The greenhouse gas dynamics of permafrost regions differ in important ways from liquid water wetlands. The microbial metabolism of soil carbon is greatly reduced when the soils are frozen for long periods. Thawing changes the availability of oxygen and liquid water, and activates bacterial metabolism, which leads to a relatively abrupt increase in emissions of either or both carbon dioxide and methane. In addition, the low solubility of methane in water causes the accumulation of this gas in bubbles under the permafrost layer. Thawing releases these bubbles, which substantially contributes to this abrupt emission increase. In permafrost regions, increased temperature will have both direct and indirect effects on wetland C storage; permafrost thaw can dramatically affect hydrology in the Arctic, but the C consequences of that change are dependent upon landscape conditions (Olefeldt et al. 2016). Permafrost thaw can lead to wetland drainage because permafrost restricts vertical water flow. As the permafrost thaws to deeper soil layers or is completely thawed, the perched water table may be lowered, resulting in drier surface soils. Permafrost-mediated wetland drainage can lead to substantial C losses because of higher rates of aerobic bacterial metabolism. However, permafrost thaw can also result in ground collapse that can cause wetland formation and substantially increase CH_4 emissions from permafrost ecosystems (Christensen et al. 2004; Natali et al. 2015; Schuur et al. 2015).

The effects of climate changes on wetland C storage will be determined largely by the extent to which the wetlands have been modified through land-use change (Petrescu. et al 2015). Altering wetlands can increase the vulnerability of the organic C pool by weakening the self-regulating feedbacks that exist in many peatland systems (Frolking et al. 2010). Land use change that affects wetland hydrology has had substantial impacts on wetland structure and function. Draining wetlands decreases CO_2 uptake and increases rates of microbial decomposition and CO_2 release (Mietten et al 2017). Soil C is also lost by peat extraction, drainage and other disturbance (Laıne et al. 2014; Evans et al. 2015; Page and Baird 2016). The hydrologic changes can be so large that they result in massive losses of C to the atmosphere, such as occurred during the fires in tropical peatlands in Southeast Asia (Page et al. 2002).

While the drainage of natural wetlands for conversion to agricultural land results in net losses of soil organic C, radiative forcing from wetland conversion depends on relative changes in the direction and magnitude of two major GHGs: CO_2 and CH_4 (Petrescu et al. 2015). Despite a decline in CH_4 emissions following wetland drainage, wetland conversion to cropland results in a significant net increase in atmospheric radiative forcing (heat trapping) (Petrescu et al. 2015). On the other hand, land use changes that cause flooding and creation of wetlands can alter C pools through the saturation and burial

of organic C (Knoll et al. 2014). Despite the potential for C sequestration, reservoir formation leads to increased GHG emissions, primarily because of CH_4 emissions from ponded water and highly fluctuating water levels in reservoirs compared to natural lakes (Deemer et al. 2016; Hayes et al. 2017).

Increased atmospheric CO_2 is projected to almost double current freshwater wetland CH_4 emissions, primarily due to warmer temperatures as well as enhanced precipitation (Shindell et al. 2004). The increase in CH_4 emissions under high CO_2 concentrations will primarily result from increased emission rates from tropical wetlands and from wetland expansion in northern high latitudes (Shindell et al. 2004; van Groenigen et al. 2011). The response of wetlands to future climate scenarios will also vary across wetland systems. For example, Wu and Roulet (2014) suggest that ombrotrophic (rain-fed) peatlands will maintain structure and function, but fen-like systems that rely on terrestrial water inputs are much more vulnerable to climate change. Land use and climate-mediated changes in CH_4 emissions from freshwater wetlands can produce a large increase in radiative forcing (heat trapping) in decades to several centuries, but in the long-term (century-millennia), C sequestration by wetlands represents, at present, a net cooling effect (Frolking and Roulet 2007; Neubauer and Megonigal 2015). However, land use, land use change, and fire can cause abrupt changes in soil C storage in wetlands, switching these long-term C sinks to sources of C to the atmosphere (Joosten et al. 2016).

Ecological Consequences for Freshwater Wetlands in a Changing Climate

Freshwater wetlands may be altered by climate change in all geographic regions of the world (Junk et al. 2013). A changed climate will alter hydrology, and functionality may be impaired by increased temperatures, drought or flooding events, CO_2 increases, and/or salinity intrusion (Junk et al. 2013). These changes will affect critical functions and ecosystem services such as carbon storage, biodiversity support, wildlife habitat and water quality (Junk et al. 2013). Negative impacts related to climate change will be compounded by synergies with other stressors, such as invasive species and land use change, thereby potentially increasing both the difficulties in managing and restoring wetlands, and the risk of endemic species extinctions (Erwin 2009).

Despite these challenges, some freshwater wetlands may be relatively resilient to climate change (Baron et al. 2002; Middleton and Souter 2016) within certain boundaries of temperature, precipitation, water level, salinity intrusion, and storm activity (Poff et al. 2002; Bernstein et al. 2007). At the same time, salinity intrusion poses specific threats to coastal freshwater wetlands because many species in these ecosystems are intolerant of salinity (Keddy 2010). Also, these species often have lower levels of production if salinity levels become too high (Middleton 1999; Sutter et al. 2014; Middleton and Souter 2016). A recent review synthesizes the state of our knowledge on how salinization associated with climate change will impact these wetlands (Herbert et al. 2015).

Climate change poses threats to non-coastal freshwater wetlands as well; hydrology is shifting as many local water regimes have become wetter or drier in recent decades (Fig. 3) (Mallakpour and Villarini 2015). In particular, megadroughts predicted by climate models (Cook et al. 2015) may dry Midwestern and Southwestern wetlands in North America with severe consequences for both wetlands and society. Severe droughts could impair the ability of these wetlands to maintain services including water quality, water supply, flood control, storm protection, and direct harvests of fish, animals, and plants, ultimately with severe negative impacts on ecosystem function and biodiversity (Baron et al. 2002; Middleton and Souter 2016). In addition, reduced winter snowpack and earlier snowmelt are impacting northern freshwater wetlands by altering the timing and magnitude of stream flows (Lawler 2009). In northern areas with permafrost, vegetation structure completely changes after permafrost melts (Malhotra and Roulet 2015). In fact, climate change is already changing community composition, species distribution, phenology, physiology and invasive species presence (Lawler 2009).

Unfortunately, many of the world's freshwater wetlands are already stressed by increased land-use pressure, so that additional hydrological alteration can contribute to an overall decrease in resilience to climate change (Baron 2002; Middleton and Souter 2016). Human alteration is commonplace throughout river corridors, challenging management as the impacts of upstream alterations accumulate along the waterway (See Fig. 4). (DuBowy 2013; Tockner and Stanford 2002). As demands for river resources increase, such problems are expected to worsen (Baron et al. 2002). Flowing water is compromised by river re-engineering practices, even though moving water generally improves oxygenation and plant health (Middleton 1999). Also, upriver freshwater extraction in tidal freshwater wetlands coupled with sea level rise can cause the salinification of surface and ground water, with accompanying stress and even the collapse of tidal vegetation in the freshwater reaches of estuaries (Perry and Atkinson 2009; Middleton and Souter 2016).

Fortunately, emerging research suggests that vegetation collapse sometimes can be avoided by hydrologic remediation (Souter et al. 2010). Freshwater remediation can reduce salinity and revive freshwater forests stressed by salinity intrusion, if the vegetation is not fatally damaged (Middleton et al. 2015; Middleton and Souter 2016). Such techniques could become critical for maintaining future ecosystem health and services (Baron et al. 2002; Middleton and Souter 2016). To date, there is no report of long-term monitoring of the survival of vegetation following remediation, so any long-term benefits are untested (Middleton and Souter 2016). Managers may need to carefully monitor the effects of traditional techniques and

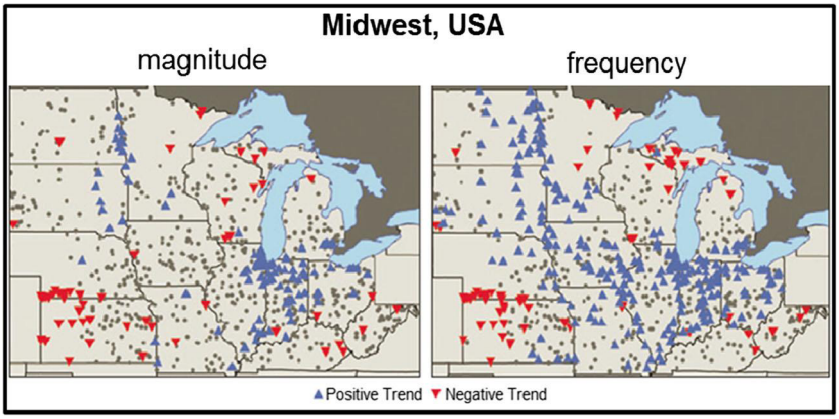

Fig. 3 The magnitude and *frequency* of flood events in the Midwestern United States from 1962–2011. Triangles show trends of flooding at U.S.G.S. gage stations with trends (positive, negative, neutral; blue triangle, red triangle, and gray circle, respectively; from Mallakpour and Villarini 2015)

adjust the timing and/or intensity of management actions accordingly (Jackson and Hobbs 2009; Middleton et al. 2017).

One harbinger of ecosystem change is that the early life history stages of foundation species (species with a strong role in structuring communities) are increasingly unsuccessful at the hot or dry edges of their ranges, noting that juveniles are more sensitive to environmental extremes than adult plants (Jackson and Hobbs 2009). Without regeneration, vegetation enters a relict state (Williams et al. 1999). Worldwide examples of relict foundation species are growing, and such vegetation may be poised for abrupt decline if disturbance removes adult vegetation (Middleton et al. 2017). There are several indicators that some freshwater wetlands are poised for collapse at the edges of their ranges, and the loss of all but relict species is a key indicator of that problem (Middleton et al 2017). Thus, freshwater wetlands face a myriad of challenges in the face of climate change.

Salt Marsh and Mangrove Response to a Changing Climate and Associated Sea Level Rise

Saltwater coastal wetlands are generally found in sheltered waters and include mangrove forests, seagrass meadows, and tidal salt marshes. These wetlands host incredibly productive plant communities, which take up substantial amounts of C via photosynthesis, and store a significant fraction of that C in their wet, anaerobic soils (Chmura et al. 2003; Donato et al. 2011; Fourqurean et al. 2012). This C has been termed "coastal wetland blue carbon." These vegetated saltwater coastal ecosystems represent an estimated 0.2% of the area of the ocean, but have C stocks equivalent to 50% of the C buried in ocean sediments (Duarte et al. 2013). As such, saltwater coastal blue C wetlands are some of the most C rich ecosystems on the planet (See Fig. 3 McLeod et al. 2011). Thus, there are growing efforts to include saltwater wetlands in international climate protection activities and policy frameworks (Wylie et al. 2016; Howard et al. 2017).

Salt marshes and mangrove swamps have accumulated C-rich soil for centuries to millennia as sea levels have slowly risen increasing levels of plant production (See Fig. 3 in McLeod et al. 2011). These wetland soils accumulate vertically through three synergistic processes (See Fig. 7 in Fitzgerald et al. 2008). The belowground growth adds volume to the soil and the aboveground portion helps trap inorganic sediment carried in tidal waters that regularly flood the soil. Extended saturation of the soil reduces the rate of decomposition of soil organic matter, thereby enabling the persistence of the effective blue C sink. Increasing soil volume results in raised surface elevation of the wetland, so that on decadal scales its elevation roughly tracks sea level rise (e.g. Chmura et al. 2001; Ellison 2008). This increase in elevation is accompanied by lateral expansion of the marsh or mangrove swamp over tidal flats in the lower intertidal zone and inland over adjacent terrestrial ecosystems. The vegetation that occupies intertidal niches has evolved a suite of mechanisms to tolerate flooding by saline water, but at a greater expenditure of energy (e.g. Mendelssohn et al. 1982). There is a limit to this tolerance.

Saltwater wetlands provide significant ecosystem services. Mangroves and salt marshes help to slow and attenuate waves and storm surge, reducing the flooding and erosion of ocean coastal communities (Shepard et al. 2011; Arkema et al. 2013). One study suggests that U.S. marine saltwater wetlands provide $23.2 billion dollars of storm protection every year (Costanza et al. 2008) while another study estimates that every hectare of salt marsh provides US $8,234 dollars, or US $3,334 per acre, in storm protection, on average, per year (Barbier et al. 2011). Since a warmer climate contributes to increased storm intensity (Trenberth et al. 2015), enhancing these protective measures is seen as a cost-effective way to protect coastal communities and infrastructure. The storm protection qualities of wetlands are leading many policy and decision makers to consider more investments in protecting or restoring coastal wetlands and other ecosystems to provide the climate adaptation benefits of natural storm and erosion reduction (Barbier 2014; Sutton-Grier et al. 2015).

The impact of climate warming, its associated sea level rise and changes in precipitation patterns will vary considerably within and among tidal marshes. Few studies have looked at combined effects of sea level rise and other aspects of climate

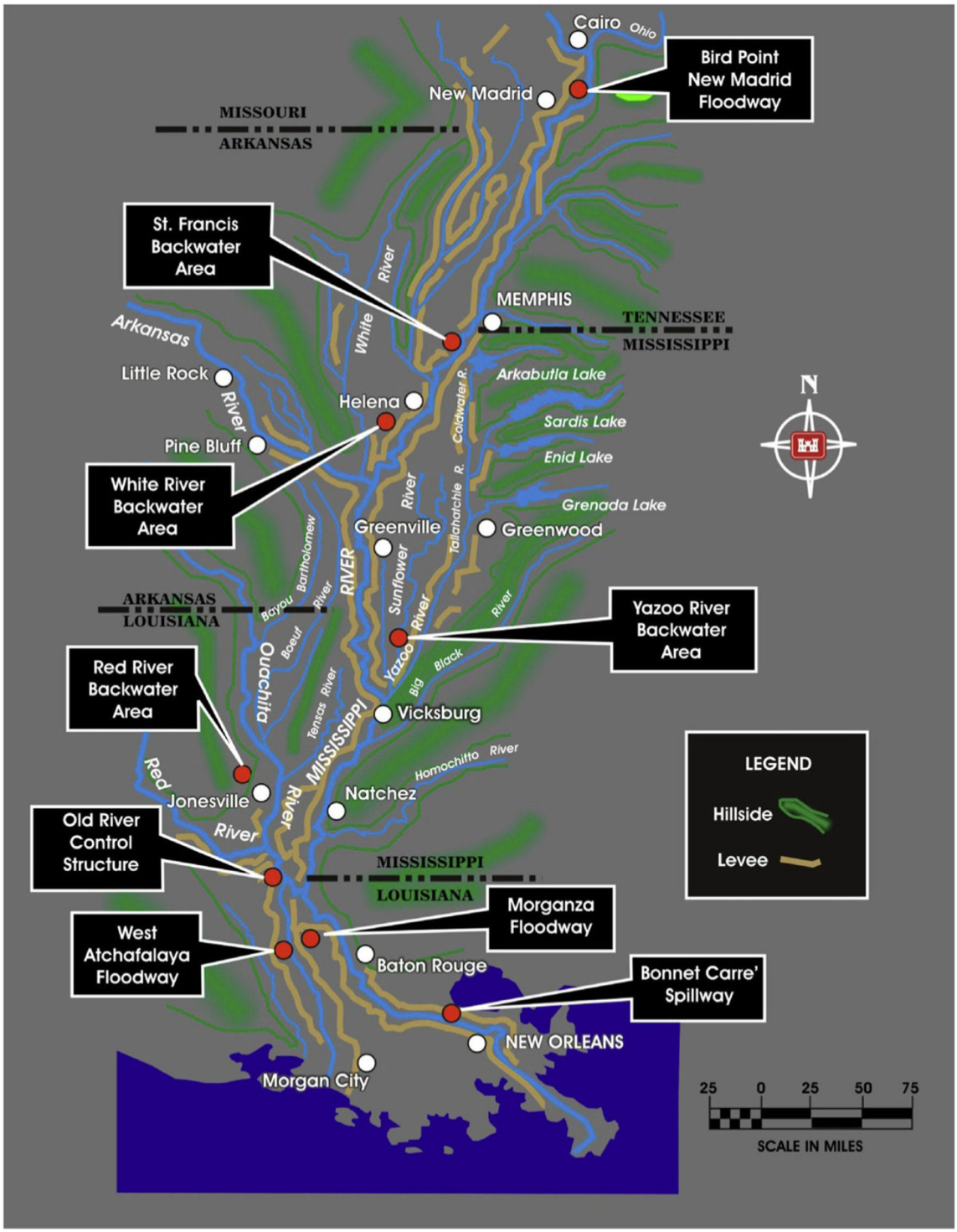

Fig. 4 The hydrologic changes in the Mississippi River and tributaries for navigation and development include straightening, deepening, levee construction and damming. These engineering practices influence ecosystem processes across the floodplain and channel of this big river system (DuBowy 2013)

change. Feher et al. (2017) reviewed the literature on the influence of changing temperature and precipitation regimes on tidal saline wetlands. They found that for several ecosystem properties and many regions there was still insufficient evidence to make generalized predictions.

Research, however, has demonstrated differences due to climate zones and vegetation. For instance, where growing seasons are limited by cold temperatures, such as the coast of the northern Northwest Atlantic, studies have shown that a warmer climate would marginally increase decomposition,

but will increase plant production and soil carbon storage (Charles and Dukes 2009; Gedan and Bertness 2010; Kirwan et al. 2014), although the effect of a rise of sea level was not addressed. On the Mediterranean coast, experimentally increased temperature, decreased precipitation and increased inundation period caused vegetation to shift from a perennial grass to an annual succulent (Strain et al. 2017).

There are two major ways that climate change is expected to impact all saltwater wetlands. Climate warming is expected to increase rates of sea level rise, resulting in loss of wetland area through "coastal squeeze," particularly in areas surrounded by urbanized uplands (e.g. Torio and Chmura 2013). This has been identified as the largest climate change threat for mangroves (Gilman et al. 2008). Secondly, warmer temperatures will allow poleward shifts in flora and fauna that can result in significant changes in the saltwater tidal habitat, thereby altering its ecosystem services, including ability to store blue C, and in some cases causing the release of CO_2 from the blue C sink as described below.

Modification of estuarine hydrology or increased rates of sea level rise can increase the hydroperiod (duration of flooding) beyond the thresholds tolerated by intertidal vegetation. Climate warming will increase rates of sea level rise primarily from continued melting of the world's ice sheets and glaciers and the thermal expansion of a warming ocean (Church et al. 2013). As the magnitude and rate of ice sheet melting is difficult to model, predicted rates of sea level rise vary, but it is accepted that increasing rates of sea level rise and its impact will be felt on all coastlines, most severely on those already subject to subsidence (sinking). One modest projection, a 0.6 m (2 ft) rise in global (eustatic) sea level by 2100, would translate to an increase of 0.61 m (2.3 ft) at New York City and 1.07 m (3.5 ft) in Galveston Texas. The greatest uncertainty is the rate of melting of ice sheets covering Antarctica and Greenland. There is nothing magical about the year 2100, and it is certain that sea levels will continue to rise for centuries under all current scenarios. A recent report considers six possible outcomes for global mean sea level rise by 2100 ranging from 0.3 meters with a 100% probability to an intermediate projection of 1.0 m with a 17% probability. If recent estimates for Antarctica ice melt are included there is a 0.1% probability that the rise could reach 2.5 m (NOAA 2017). See Fig. 5.

Within tidal wetlands the effects of increased rates of sea level rise will be most strongly felt at the lower elevations where vegetation will most rapidly succumb and soil accretion will cease (e.g. Kirwan et al. 2010). Without living vegetation, the submerged wetland soil and its C stock can be exposed to erosion and possibly to oxidation of the organic matter, returning centuries of stored CO_2 back to the atmosphere. The fate of soil organic matter eroded from wetlands is an increasingly important science question that is not yet resolved (e.g. DeLaune and White 2012). If the upland adjacent to the tidal wetland is not developed and slopes are gentle, then the wetland can migrate inland, limiting the loss of area (but not necessarily blue carbon stocks). However, if this land is developed or if natural topography is steep, the structures or grade will prevent migration, putting the marsh or mangrove in a coastal squeeze (Torio and Chmura 2013). The potential for coastal squeeze is high on many of the world's coastlines, particularly on the highly urbanized bays and estuaries of the U.S., such as San Francisco Bay in California and the shore of New York City on Jamaica Bay (Hopper and Meixler 2016). The loss of wetland area due to coastal squeeze means loss of all its ecosystem services including essential habitat for fish and wildlife, loss of the ability of the system to store additional C and loss of its capacity to buffer inland development from the impacts of storms. One opportunity to decrease the amount of salt marsh loss that is likely to occur with sea level rise is to actively plan for future inland marsh migration now. There have been a few innovative studies considering how to plan for marsh migration including one that examined which wetlands along the Gulf coast of the U.S. are most threatened by projected future urban development. This information can be used to identify migration corridors for these wetlands and set priorities for current protection to prevent future coastal squeeze (Enwright et al. 2016). Another study examined two conditions to determine which marshes along the U.S. Northeast and Mid-Atlantic coast are likely to be resilient to sea level rise by examining the current health of the marsh as well as its potential to migrate inland (Anderson and Barnett 2017).

Climate warming has a direct impact on salt marshes and mangrove swamps by increasing poleward migration of their flora and fauna. Such changes are most observable where

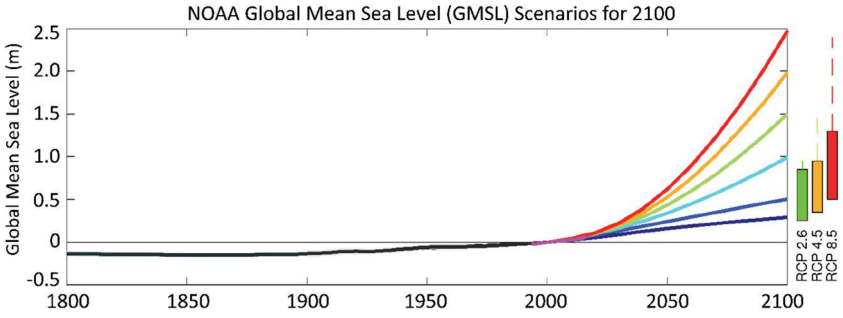

Fig. 5 Past and projected changes in global mean sea level rise. (NOAA 2017a). Mean sea level rise and projections to 2100 under alternative IPCC scenarios. The lowest rise is 0.30 meters (100% probability), the intermediate is 1.0 meters (17% probability) and the highest is to 2.5 meters (0.1% probability)

species' populations occur near the edge of their biogeographic ranges. In fact, globally, mangroves are expanding their range from tropical and subtropical climes, to invade salt marshes on adjacent warm temperate coasts (e.g. Godoy and DeLacerda 2015). Studies are finding that climate-changed-induced movement of mangroves into saltmarsh with warming temperatures is resulting in increases in the carbon stored in biomass and soils in marine and estuarine mangroves. This is because mangrove forests have some of the highest average C storage per land area in unmanaged terrestrial ecosystems (Doughty et al. 2015, Kelleway et al. 2015). As mangroves replace salt marsh vegetation, soil C may increase (Bianchi et al. 2013). However, such invasions significantly change habitat structure and we know little about impacts on biotic interactions, potential lags for co-evolved species to shift, or challenges to mosquito control management (Dale et al. 2013). While SLR is expected to enable mangroves to migrate inland where other obstacles do not occur, the example of mangrove dieback in northern Australia (Duke et al. 2017) shows that the impact of climate is more complex, with changes in the regional climate patterns resulting in lower rainfall and tidal depression during the hot part of the year being suggested as the cause of the dieback.

Several studies have documented that increasing salinity in upstream reaches of an estuary will decrease biomass accumulation of foundation freshwater plant species (Sutter et al. 2014, 2015; Neubauer et al. 2005). In microcosm studies, Sutter et al. (2015) found that even smooth cordgrass (*Spartina alterniflora*), a salt marsh foundation species on the western Atlantic, had reduced growth when exposed to increased salinity and grown with the invasive strain of tall common reed (*Phragmites australis*).

An example of range extension of benthic fauna is found in the herbaceous salt marsh fiddler crab (*Uca pugnax*) that burrows in marsh soil. Historically, the range of the fiddler crab has been limited along the northwestern Atlantic coast to waters south of Cape Cod, Massachusetts. Its range recently has expanded northward where it has been observed on the coast of New Hampshire (Johnson 2014). The effect of fiddler crabs on C storage has been studied in Virginia salt marshes where Thomas and Blum (2010) found that 74% more root material was decomposed in marshes with fiddler crab burrows. Unless potential predators and competitors accompany crab migration, this range extension could lead to significant release of CO_2 to the atmosphere from northern salt marsh C sinks.

Saltwater wetlands are effective natural C sinks until they are disturbed, degraded, or destroyed by draining them for urban development, agriculture, aquaculture or by other means. Rising sea levels will also degrade these ecosystems. Disturbing wetland hydrology can enable oxygen to oxidize stored soil organic matter. Drying wetland soils increases microbial decomposition of stored organic C causing these natural sinks to become sources of CO_2 emissions (Pendleton et al. 2012). Preventing loss of these ecosystems is a priority to avoid additional GHG emissions. Restoring degraded or lost saltwater wetlands can regenerate their ability to remove and sequester CO_2 from the atmosphere.

Part 2: Emerging Policies and Management Strategies for Protection of Wetlands and Their Ecosystem Services in the Context of a Changing Climate

At all levels of government, policies and management strategies that reference the relationship between wetlands and climate change may be found both in entities and policies that primarily focus on wetlands and in those that primarily focus on climate change. While wetlands are not mentioned explicitly in any of the formal climate change treaties, their relevance may be inferred under the definitions of "sources, sinks and reservoirs" for GHGs. More recently, they have been mentioned explicitly in a North American agreement among three heads of state. Wetland scientists, policy makers and managers can therefore utilize both wetlands and climate change policies and management strategies.

Recommendations for policy and management address both the role of wetlands in climate regulation, such as conserving and sustainably managing stored carbon (Nahlik and Fennessy 2016), and the role of wetlands in provision of ecological and human community climate adaptation and resiliency ecosystem services. Resiliency functions and services include flood storage, buffering of storm damage, protecting water quality by filtering pollutants and sediment out of runoff generated by severe storm events, groundwater recharge and provision of water supply during drought, provision of wildlife refuges and corridors and maintenance of biodiversity (Junk et al. 2013; Association of State Wetland Managers 2015a; Narayan et al. 2016), regulating microclimate (Zhang et al. 2016) and physically buffering coasts from sea level rise and increases in storm surges (Millennium Ecosystem Assessment 2005), as well as others enumerated elsewhere in this article. Anderson et al. (2016a) state, "Protecting wetlands and riparian corridors has been suggested as one of the single best actions in promoting resilience and in sustaining biodiversity (Naiman et al. 1993, Fremier et al. 2015)".

International Wetland and Climate Policy

In the following sections, we explore several examples of how international policy can influence the management and protection of wetlands, including their climate mitigation and adaptation/resiliency benefits, with examples from the climate policy setting (IPCC Wetlands Supplement, UN Framework Convention on Climate Change, Paris Climate Agreement, Secretariat of the Pacific Regional Environment Programme, (SPREP), The European Union Water Framework Directive and North American Action

plan, and one from the wetlands policy setting, Ramsar). Wetlands sit at the intersection of three Sustainable Development Goals: Number 13, Climate Change; number 14, Life Below Water; and number 15 Life on Land (Sustainable development goals 2015).

Climate Treaties: Greenhouse Gas Inventories and Related Mechanisms

Initial steps to incorporate wetlands into international climate policies are now in place. In 2013, the Intergovernmental Panel on Climate Change, which provides guidance to countries on how to compile their national GHG inventories, released a Wetlands Supplement (IPCC Wetlands Supplement 2014). Previous IPCC guidance did not include comprehensive information on accounting for wetlands as sources and sinks because it was determined that the science of these ecosystems was not sufficient to provide Tier I (basic) methodologies for how to include them in national inventories. The Wetlands Supplement provides guidance on how countries are to include explicitly the emissions from land use change in freshwater wetlands, including peatlands and saltwater wetlands, in their national inventories. At least 8 countries identified peatlands as playing a role in their intended Nationally Determined Contributions (NDCs): Belarus, Colombia, France, Indonesia, Malaysia, Mongolia, Peru, and Republic of Congo (NDC Registry 2016).

Although countries are not required to use the Wetlands Supplement, they were encouraged to do so and in the 2017 submissions, a few countries, including the U.S. (USEPA 2017), did include wetland emissions in their national GHG inventories. While not requiring C accounting from wetlands, the Wetlands Supplement is a step forward in terms of enabling countries to account for the C fluxes associated with wetland ecosystems and moves the world closer to requiring countries to account for the substantial emissions from these ecosystems when they are disturbed or destroyed (for more details see Sutton-Grier and Moore 2016).

There are additional mechanisms within the United Nations Framework on Climate Change (UNFCCC) regime where coastal blue carbon ecosystems, and other wetlands might be included in climate policies: Reduced Emissions from Deforestation and Degradation (REDD+), Clean Development Mechanism (CDM), and Nationally Appropriate Mitigation Actions (NAMAs) (Gordon et al. 2011; Herr et al. 2012). Traditionally, these mechanisms have focused more on terrestrial forest projects, but could include saltwater and freshwater wetlands if projects can be developed that demonstrate the effectiveness of wetlands for emissions reductions.

Reduced emissions from deforestation and forest degradation (REDD+) provide payments to restore and protect forest C reservoirs in developing countries to avoid CO_2 emissions (REDD 2016). The wetlands that meet the requirements would be wetland forests and mangroves. The CDM develops projects in developing countries that reduce emissions and enable those countries to sell emission reduction credits to markets like the European Trading System (CDM 2017); these projects could include coastal wetland restoration or protection projects that would help a country reduce emissions. NAMAs refer to *any* action that reduces emissions in developing countries and must also be part of a national governmental initiative (http://unfccc.int/focus/mitigation/items/7172.php) and therefore have government approval. As such, NAMAs provide a flexible framework that can permit developing countries to meet their nationally determined contributions under the Paris Climate Agreement to reduce GHG emissions as part of their development strategy. This provision has the potential to include emissions reductions from saltwater wetlands, since each country is free to define what appropriate NAMA projects are and how they are funded (NAMA 2017). There is one blue carbon NAMA project being developed in the Dominican Republic (Sutton-Grier et al. 2018). Further demonstration projects are needed to show which of these mechanisms are feasible and most effective for saltwater wetlands.

Secretariat of the Pacific Regional Environment Programme

The Secretariat of the Pacific Regional Environment Programme (SPREP) has positioned climate change as a priority under the Strategic Action Plan 2017-2026 (SPREP 2017). It is further seen as a crosscutting issue and comprises programs on adaptation, mitigation, policy and science. Addressing climate change is seen as a priority as it is already disproportionally affecting the islands of the Pacific, including impacting mangroves and freshwater wetlands (Ellison 2011; Nurse et al. 2014). Engagement with the Ramsar Convention has been renewed given the importance of wetlands in the Pacific islands and their role in climate change and disaster risk reduction.

European Union

The European Union has a robust suite of environmental legislation and policies with increased efforts towards the incorporation of climate change and coherence with other sectors. However, there are gaps in implementation and some work is still needed to ensure the resilience and sustainability of water resources (Francés et al. 2017). The European Union has considered the ecological condition of all water bodies, including wetlands, through the Water Framework Directive with an emphasis on the future protection and improvement of the water environment as essential for sustainable development. While the Directive did not specifically include climate change there have been many investigations into how climate

change will alter aquatic ecosystems, including numerous actions, strategies and policy instruments, as well as monitoring, reporting and evaluation systems, that could significantly contribute to a broader and more comprehensive view of climate change impacts and adaptation in the water sector (Finlayson et al 2018). As the Directive will be revised in 2019, it is anticipated that climate change will be implicitly addressed as an anthropogenic pressure, and supported with common guidelines and approaches for considering resource costs and adaptation measures (Francés et al 2017). The vote by the European Parliament in January 2018 on the Renewable Energy directive called for increases in forest bioenergy and biofuels with few limitations on the consequences for wetland forests and ecosystems despite letters from scientists urging constraints (European Parliament 2018, Scientists letter 2018, Duffy et al. 2018).

North American Climate, Clean Energy, and Environment Partnership Action Plan

In June, 2016 Prime Minister Justin Trudeau of Canada, President Barack Obama of the United States and President Enrique Peña Nieto of Mexico announced the North American Climate, Clean Energy, and Environment Partnership Action Plan which explicitly identifies blue carbon preservation and restoration as mitigation actions, and the value of wetlands for climate resiliency ecosystem services, stating the intention to, "enhance the conservation and restoration of wetlands, which increase mitigation actions (blue carbon), preserve coastal ecosystems services, and reduce the potential impacts of more frequent or intense severe weather events under climate change projections" (North American Climate, Clean Energy, and Environment Partnership Action Plan 2016).

Ramsar Convention

Since 1975, the Ramsar Convention on Wetlands has provided an international policy framework for wetland management (Gardner and Davidson 2011). It comprises 169 Contracting Parties (national governments) that generally meet every 3 years to consider the state of the world's wetlands and agree on priority actions in support of the Convention's mission which is to act for the "conservation and wise use of all wetlands through local and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world." As outlined by Davidson (2016), the Convention is implemented through three "pillars": the wise use of all wetlands; the designation and management of Wetlands of International Importance (Ramsar sites), including reporting on adverse change; and international cooperation, including for shared wetlands.

Each contracting party commits to designate and manage a coherent and comprehensive national network of Ramsar sites. As of 25 February 2018, the global network of 2301 Ramsar sites covers a surface area of 2.25 million km^2 or 18.6% of the most recent and reliable estimate of global wetland area (Davidson et al. 2017). This achievement represents one of the major successes of the Convention. However, efforts to maintain other wetlands have not been as successful with high rates of loss and degradation recorded throughout the 20th Century up to the present time (Davidson 2014; Gardner et al. 2015). These general outcomes show that the Contracting Parties have had mixed success in meeting their commitments which is not surprising when fewer than half have reported activities that demonstrated how they were addressing the goals and strategies in the Convention's Strategic Plan (Finlayson 2012). The consequences of climate change for wetlands is expected to place further pressure on the ability of Contracting Parties and wetland managers to meet such goals and strategies in the future.

The Convention has recognized the significance of wetlands in managing global GHG emissions and in providing climate resiliency in addition to traditionally acknowledged ecosystem services. In 2012 and 2015, the Conference of Parties recommended a number of actions by the Parties, including:

- recognizing significant peatlands as Wetlands of International Importance in recognition of their role in C sequestration and storage,
- recognizing the significance of coastal blue carbon,
- recognizing the role of wetlands in providing climate resiliency services,
- recognizing the unique vulnerability of wetlands to changes in climate (Ramsar COP12 (2015) Resolution XII.11; Ramsar COP11 (2012) Resolution XI.14; Barthelmes et al. 2015).

Finlayson et al. (2017) built on the recognition that wetlands were vulnerable to climate change and examined how climate change would influence international policy-making for wetland management, and identified potential adaptation responses that may assist Contracting Parties to better meet their commitments under the Convention.

The Convention, though, has not provided specific guidance on how to meet these requirements in the context of climate change, such as how to identify appropriate reference conditions (Finlayson et al. 2016; Gell et al. 2016) and whether past reference conditions were indeed suitable under the changing conditions of the Anthropocene (Kopf et al. 2015). This lack of guidance has left important gaps in wetland policy concerning:

- how objectives and targets for wetland conservation and management could be set and revised in the light of climate change,

- how wetland management could best address the uncertainties due to climate change,
- how managers could best monitor and evaluate the condition of wetlands that are responding to climate change,
- whether adverse change in ecological character due to climate change should be subject to the same reporting requirements.

The Australian Government has decided that it would not use the existing formal mechanisms for reporting adverse change in Ramsar sites when it was caused by climate change. This policy raises unanswered questions about the usefulness of the formal reporting mechanisms under the Convention for dealing with adverse change when caused by global pressures such as climate change. This position creates a paradox for the Convention whereby it recognizes the vulnerability of wetlands to climate change, but has not addressed the implications for its reporting mechanisms nor provided wider guidance for management given the pervasiveness of climate change as a driver of change in wetlands.

Addressing these issues will close a major gap in the guidance provided by the Convention and provide wetland managers with advice on how to respond to the deteriorating condition of wetlands worldwide (Gardner et al. 2015). Without active intervention a changed climate is expected to exacerbate the deterioration (Finlayson et al. 2006). These principles further provide support for wetland managers seeking to determine the significance of ecological change in the face of climate change, given that the Ramsar Convention has not provided guidance to address what is becoming an overarching driver of adverse change in wetlands. While international policy, such as that provided by the Ramsar Convention, can guide countries towards effective management choices, the policy responses and management itself are required at national and sub-national levels. Policies determined at the international level require national and sub-national implementation.

National Policy Setting

National policies, whether wetland or climate change, can have important impacts on wetland conservation or destruction and therefore on the ability of a country's wetlands to either contribute to climate change mitigation, adaptation and resiliency, or become additional sources of GHGs to the atmosphere. National policies also determine the effectiveness of international policy, such as those instituted by the Ramsar Convention (Finlayson 2012). Contracting Parties to the Ramsar Convention have been encouraged to develop national wetland policies; however, in 2012, fewer than 50% reported that they had developed such policies (Finlayson 2012). The relative lack of national wetland policies limits opportunities for climate change to be addressed at the national level, as it relates to wetlands. Furthermore, there is limited evidence that climate change has been specifically addressed in national wetlands laws and policies that do exist. Pittock et al. (2010) point to gaps and inconsistencies in managing wetlands under climate change with the example of the Murray-Darling Basin in Australia where climate change has not (yet) been included in water planning instruments despite a large financial investment in riverine restoration focused on water reallocations and steps to return water to the rivers and wetlands (Pittock 2013). Wetland and climate scientists, managers, and policy makers could work together to fill this gap, while in the meantime, finding opportunities within existing wetlands and climate change laws at all levels of government (from international to local) to manage and protect wetlands in a climate-informed manner.

In the United States, "Recommendations for a National Wetlands and Climate Change Initiative" (Christie and Kusler 2009) provides specific recommendations for the development of climate change policy within wetlands programs at the national, sub-national/state, and local levels. Although written for the U.S. policy setting, many of the recommendations could be implemented in other countries as well. U.S. federal agencies included wetlands and other ecosystems into climate change planning and policies in October 2014. The White House's interagency Council on Climate Preparedness and Resilience (Resilience Council) Climate and Natural Resources Working Group (CNRWG) released their "Priority Agenda for Enhancing the Climate Resilience of America's Natural Resources (Priority Agenda)". The Priority Agenda identifies a suite of actions the federal government planned to take to enhance the resilience of America's natural resources to the impacts of climate change and promote their ability to absorb CO_2. Wetlands were incorporated into the Priority Agenda, including specific actions related to coastal blue carbon requiring the National Oceanic and Atmospheric Administration (NOAA) to lead a baseline study on carbon in saltwater wetlands. This baseline study became the foundation for the U.S. to include saltwater wetlands in the national GHG inventory in April 2017 (USEPA 2017). This represents important progress in tracking and managing saltwater wetlands and GHG emissions because every subsequent U.S. inventory will include saltwater wetlands each year (Sutton-Grier and Moore 2016).

Sub-National and Regional Policies, Strategies and Management Tools

We now provide examples of policies, strategies, and management tools being developed at the sub-national level to address the challenge of climate change. Reflecting an understanding of the climate mitigation functions of wetlands and other ecosystems, the Government of Ontario, with the passage in 2010 of the Ontario Far North Act (Ontario Laws 2010) became the world's first political jurisdiction to enact legislation (as

opposed to policy/guidance) that recognizes the explicit role of wetlands and other ecosystems in the global C cycle by stating as the third of four objectives that land-use planning ensure "the maintenance of biological diversity, ecological processes and ecological functions, including the storage and sequestration of C in the Far North". This sets a good example of regional leadership on wetland management and climate mitigation.

In the United States, the Association of State Wetland Managers survey of state wetland programs (Zollitsch and Christie 2015) indicates that 17 states report working within the wetlands programs formally to address climate change, 13 states report working informally to address climate change, 17 states report no climate change work, and data was unavailable or unknown for 3 states. Some of the states with no designated climate related projects within state wetlands programs reported that such activity is occurring at the regional and/or local level, and that "non-climate change" work aimed at addressing natural hazards and extreme precipitation events is occurring at the state level (Association of State Wetland Managers 2015b). Two examples of states that have established climate policies or plans that proactively address wetlands are discussed below.

A Massachusetts Executive Order (Massachusetts Executive Order #569 2016), establishes a process for a statewide integrated climate change strategy and requires a framework and technical assistance for every town and city in the state to complete climate vulnerability assessments, identify adaptation strategies and begin implementing these strategies. Although wetlands and ecosystems are not specifically mentioned in the Executive Order, it is being implemented with a focus on nature-based solutions that encompass wetlands. The lesson here is that opportunities for wetland protection and restoration exist within broader climate resiliency and GHG reduction programs. A cross-disciplinary process and collaboration integrates wetlands into broader responses to the climate challenge. Such cross-disciplinary collaborations require that a broad spectrum of policy makers and managers become educated about the importance of wetlands in our response to climate change.

Massachusetts laid the groundwork for current responses by initially addressing wetland and community vulnerability to changes in climate by identifying climate impact reduction strategies in the Massachusetts Climate Change Adaptation Report (Massachusetts Office of Energy and Environmental Affairs and the Adaptation Advisory Committee 2011). The ensuing climate change strategic planning process now also requires updated coastal floodplain regulations.

The state of Michigan has developed a Climate Change Adaptation Plan for Coastal and Inland Wetlands in the State of Michigan (Christie and Bostwick 2012), which identifies climate impacts to wetlands, surveys similar efforts in other states, discusses the role of wetlands in climate mitigation and adaptation, suggests approaches for integrating wetlands into the broader Michigan Climate Action Council Climate Action Plan that establishes the framework for Michigan's comprehensive response to climate change, and provides recommendations for managing wetlands in the context of climate change.

Within the context of conventional wetland regulations in the U.S., protection of wetlands is in part dependent upon delineation of wetland boundaries, which can shift during periods of drought due to die-off of wetland vegetation. As climate changes, the incidence of drought is increasing in some regions, thus putting at risk areas that typically would be protected by wetland regulation. The US Army Corps of Engineers (USACE) North Central and Northeast Region recognizes this by allowing for modification of wetland delineation criteria during drought (i.e. less reliance on vegetation present during drought) (USACE 2012). Similar provisions could be developed in other jurisdictions elsewhere around the world, so that land that functions as a wetland under regular climate conditions is not excluded from protection or regulation during a temporary drought. This applies to ephemeral wetlands especially those that may already experience long periods of drought that may be extended as the climate changes.

Science-based wetland and natural resource management decision-making can be adjusted to incorporate the effects of climate change on ecosystems. The Nature Conservancy (2017) has created a GIS-based mapping tool, through their Resilient and Connected Landscapes project, that maps ecologically climate-resilient and connected land in regions of the U.S. and Canada (Anderson et al. 2016a, b). Users can identify land with relatively high levels of geodiversity (i.e. diversity of bedrock, soils, and elevations), landform diversity (i.e. topographic diversity and density of wetlands), and connectedness. When combined with mapping of ecological integrity/biological condition, this tool identifies land most likely to maintain high ecological function as climate changes (Open Space Institute and North Atlantic Conservation Cooperative 2016), and thus allows the user to prioritize conservation investments in the context of a changing climate. Because wetlands create temperature and humidity gradients on the landscape, TNC prioritizes landscapes with a high density of wetlands as being more resilient, other factors being equal. Additionally, these maps allow wetland scientists to understand the likely long-term ecological viability of wetlands in a larger landscape context.

Local and Project-level Strategies and Best Management Practices: Application of Carbon Management and Climate Resiliency Science

Many authors have assessed the amount of C that can be accumulated in wetland soils to address climate change.

Some, such as Page and Baird (2016) have carefully considered the evidence and pointed to the uncertainties as well as the strengths of such evidence for particular peatland ecosystems.

Conserving, restoring, and halting disturbance of wetlands, and creating saltwater wetlands, are essential for maintaining the existing terrestrial C sink and supporting natural processes that sequester C from the atmosphere into wetland soil and biomass. Increasing wetland productivity would also help if means for doing so across large areas could be found. If a goal is to increase the amount CO_2 sequestrated by wetlands, it is worth considering how much wetland restoration or creation would be needed to make a significant difference. The annual amount of CO_2 sequestered by wetlands can be estimated using the data provided by Bridgham et al. (2006) for the annual average rate of C sequestration by wetlands (~23 $gCm^{-2}y^{-1}$), and the most recent estimate of the global wetland area (12,100,000 km^2) provided by Davidson et al. (2017). Using these values, the annual amount of CO_2 sequestrated is equivalent to 278 $TgCy^{-1}$. This equals 6% of the current 4.4 $PgCy^{-1}$ net annual increase in atmospheric CO_2. Hence, the area of new wetlands needed to remove one percent of the current annual increase in atmospheric CO_2 is about 2,000,000 km^2; an increase of about 17%. This is only a very approximate estimate as the rate of sequestration is not equal across all wetlands, and it does not take into account the time period for restored or created wetlands to reach this rate. While these calculations make simplifying assumptions about C content and rates of sequestration, they demonstrate the importance of retaining existing wetlands, particularly vulnerable high-C sequestering wetland types such as saltwater wetlands, forested wetlands, peatlands, and permafrost, as carbon sinks, and curbing temperature rise to avoid releasing GHGs as wetlands warm.

Moving forward, it is important to examine new approaches to wetland management and governance. There is a strong potential to generate new private investment in saltwater wetland restoration and management efforts by linking these projects to the voluntary and compliance C markets. For example, a "Methodology for Tidal Wetland and Seagrass Restoration" (VM0033) was approved in 2015 by the Verified Carbon Standard (VCS). This methodology provides a means for managers and voluntary carbon market project developers anywhere in the world to initiate tidal saltwater wetland restoration projects for GHG credits. The methodology includes project eligibility criteria for receiving voluntary carbon credits and accounting procedures within voluntary markets, and is available for use for carbon crediting by projects that have net benefits when compared to the baseline scenario (e.g. CO_2, CH_4, and N_2O). This methodology can be used globally by project developers to generate GHG (carbon) credits for tidal wetland and seagrass restoration activities and used by the saltwater coastal restoration and management community to begin to design projects.

The American Carbon Registry (American Carbon Registry 2017) has approved a few C credit methodologies for wetlands in the Gulf of Mexico, and California's GHG cap-and-trade program incorporates C credits from rice cultivation activities (California GHG cap and trade California Cap and Trade 2017). The development of these voluntary carbon market methodologies is a critical step toward facilitating C credits in support of saltwater coastal restoration. At current voluntary carbon market prices, revenue generated from the voluntary carbon market is likely not enough to pay for the full costs of saltwater coastal restoration projects; however, C financing can act as an incentive for additional investment in, or joint funding of, saltwater coastal restoration, and can provide key support for long-term project monitoring. Further details are provided by Sutton-Grier and Moore (2016).

Thinking globally and acting locally, wetland managers can incorporate carbon management and climate resiliency science into project-level work (including developing a body of climate-related Best Management Practices), whether or not governing policies and regulations exist. As noted earlier in this article, avoidance of impacts to wetlands, and associated carbon stocks and processes, is likely to be the most effective management practice for preventing increases in GHG emissions from wetlands, protecting climate resiliency functions, and protecting traditional wetland ecosystem services, and it is therefore important for managers to understand the underlying science. The vast majority of wetlands store more carbon than they release to the atmosphere on an annual basis, and thus are net C sequesterers. Recently *created* freshwater wetlands may, in many cases, have a net warming effect because the cumulative radiative forcing from increased CH_4 emissions exceeds the reduction of radiative forcing from sequestered CO_2 until there is a "switchover point." Once the radiative forcing (now a reduced value) of sequestered CO_2 exceeds the radiative forcing by emissions from CH_4 and N_2O, the created freshwater wetland has a cooling effect on climate. It may take decades to thousands of years to reach the switchover point (Bridgham et al. 2014; Neubauer 2014; Neubauer and Megonigal 2015). The findings in these studies highlight the impact of time on soil structure, microbial communities and rooting, and associated GHG emissions from wetlands. This reinforces the importance of protecting existing wetlands wherever possible to maintain their climate mitigation (and other) functions. On the other hand, because the biogeochemistry of saltwater wetlands is different from that of freshwater systems, restored or created saltwater wetlands become C sinks that reestablish their climate mitigation benefits rapidly.

It is important to find Best Management Practices that can minimize GHG emissions during freshwater wetland restoration and creation projects at the local level. Common practice in freshwater wetland creation is for soils to be composed of

composite mixes or from soils that have been removed from wetland impact areas and are then stockpiled, re-applied to the created wetland, and planted with nursery stock and seed. Typically, these soils are structurally and functionally disrupted by heavy machinery and stockpiling, which provides an opportunity to oxidize SOC and cause loss of soil structure and microbial communities. The disruption of soil structure and microbial communities resets the ecological clock, thus reducing or eliminating the beneficial effects of time on soil biogeochemical processes (Janzen 2016). Several studies indicate that transplanting intact wetland soil and/or vegetation to wetland restoration or creation sites reduces GHG emissions, compared to common practices noted above (Wilhelm et al. 2015; Murray et al. 2017; Cagampan and Waddington 2008; Waddington et al. 2009). Brown and Bedford (1997) found that transplanting intact blocks of wetland soil results in more successful establishment of wetland species, while reducing the presence of invasive plants during restoration of drained wetlands. In cases where wetland impacts are unavoidable, transplanting intact impact area O and A horizons (i.e. the upper soil layers with high SOC content) that contain intact herbaceous and shrub vegetation to the wetland creation site may facilitate C storage, climate resiliency, and traditional ecosystem services by transplanting soil structure, microbial communities, and rooted vegetation. Where the wetland restoration or creation site is in relative proximity to the wetland impact area, costs are likely to be reduced compared to traditional wetland construction costs by moving impact area soil only once, avoiding costs associated with stockpile sedimentation and erosion control, and avoiding or reducing nursery stock and seed purchases.

More research on the scale of potential GHG benefits associated with transplanting relatively intact O and A soil horizons and relatively intact surface vegetation is needed. The US Army Corps of Engineers (USACE) New England District mitigation guidance document refers to "block transplanting" (USACE 2010), but does not identify the importance of protecting the complete O and A soil horizons, or the role in C protection and GHG emission minimization. Wetland scientists and managers could include incorporation of climate resiliency and GHG management strategies into specific projects, as well as provide education on ecological climate resiliency, ecological C management, and climate change communication to a broader audience.

Conclusions and Recommendations

This article documents recent research that demonstrates the important role that wetlands play in moderating climate change and protecting communities from the impacts of a changed climate system. At the same time, these wetland ecosystems are particularly vulnerable to changes in climate. Meeting the Paris Climate Agreement temperature goals can only be achieved in practice by greatly reducing emissions of GHGs into the atmosphere and simultaneously, actively removing CO_2 from the atmosphere. Yet many wetland scientists, ecosystem managers and natural resource policy-makers are unaware of the important C storage role of wetlands, and how to incorporate C-cycle considerations into wetland management and policy. Meanwhile, many climate scientists, as well as national and international policy makers, undervalue the role that wetland management might play in the future trajectory of climate change on the global scale and do not require reporting of wetland emissions or removal of GHGs (IPCC Wetlands Supplement 2014).

To play a more effective role in climate change mitigation and adaptation/resiliency, wetland scientists need to clearly communicate the significance of wetlands to the wellbeing of society and the economy. Communicating with policy makers and the public requires aligning wetland science and specific climate mitigation and adaptation/resiliency ecosystem services with the concerns and mindset of the audience (Leiserowitz et al. 2015, 2017; Roser Renouf et al. 2016; Yale Program on Climate Change Communication (YPCCC 2017); Center for Research on Environmental Decisions 2009). Studies by Cook et al. (2013, 2016) document that 97% of climate scientists agree that anthropogenic climate change is occurring. The near universal agreement among climate scientists can create confidence in the public to support action, but in addition, it is essential to make clear the science that is behind the consensus. Similar findings are documented by several other studies (Doran and Zimmerman 2009; Anderegg 2010; IPCC Wetland Supplements 2014). While TNC resiliency mapping, referred to earlier, and YPCCC research is specific to the U.S.A. and Canada, the concepts underlying their work can be applied around the world to develop wetland-related ecological climate resiliency mapping, and communicate effectively about climate change and wetlands.

The important role that wetlands play in sequestering C from the atmosphere needs to be better appreciated by wetland and climate scientists as well as by policy makers. Climate is a global issue, and the policy section of this paper illustrates the importance of incorporating both wetlands and climate change into international agreements. On the other hand, all wetlands are local and require protection or restoration at appropriate regional and local scales. We identify examples of policies that direct management practices at those scales, thus creating a multilayered management structure for maximum effectiveness (Moomaw et al. 2016). This coordinated approach can provide resilient wetland ecosystem services and protect communities using policies that buffer wetlands from climate impacts while addressing global climate change itself. Transdisciplinary research that integrates local wetland conservation with global climate change provides an important

tool for stabilizing "greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (UNFCCC 1992).

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Compliance with Ethical Standards

Conflict of Interest The authors declare no conflict of interest with any data, information or analysis provided in this manuscript. Any use of trade, firm or product names is for identification purposes only and does not imply endorsement by the U.S. Government or any of the author's institutions.

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Thank you to EEA, the CFC Expert Panel, and all our highly skilled and professional agency partners at DCR and MassWildlife your dedication to serving the diverse needs of people and landscapes across the Commonwealth. There are several recommendations of the Forests as Climate Solutions Initiative that Mount Grace Land Conservation Trust (Mount Grace) supports, including that Massachusetts' landscape history should be considered when establishing goals; that flexibility is needed and agencies must be empowered to make considered decisions informed by public input; and that forests must be simultaneously managed for carbon sequestration and other benefits. We especially appreciate your commitment & additional resources to support conservation as a climate solution.

Mount Grace is committed to working with our agency and conservation partners to collaborate on the implementation of these recommendations in 2024 and beyond. While it remains unclear just how these recommendations will be implemented, public-private landscape partnerships provide highly valuable on-the-ground examples of how we can work toward the multifaced goals of climate solutions, forest diversity, multi-scaled partnerships, and forest resilience.

Regarding expert panel decision-making and stakeholder engagement as the CFC recommendations are implemented, Mount Grace would like to see more multi-disciplinary representation from experts in wildlife conservation, forest biometrics, biodiversity, hydrology, conservation biology and other related fields. We feel these fields of expertise were underrepresented on the CFC panel. Massachusetts' forests, communities, and biodiversity will all benefit from more representation in these fields of expertise as Executive Order 618 is implemented, as the CFC recommendations are implemented, and as panels like the Forest Reserve Scientific Advisory Committee and others are updated and expanded.

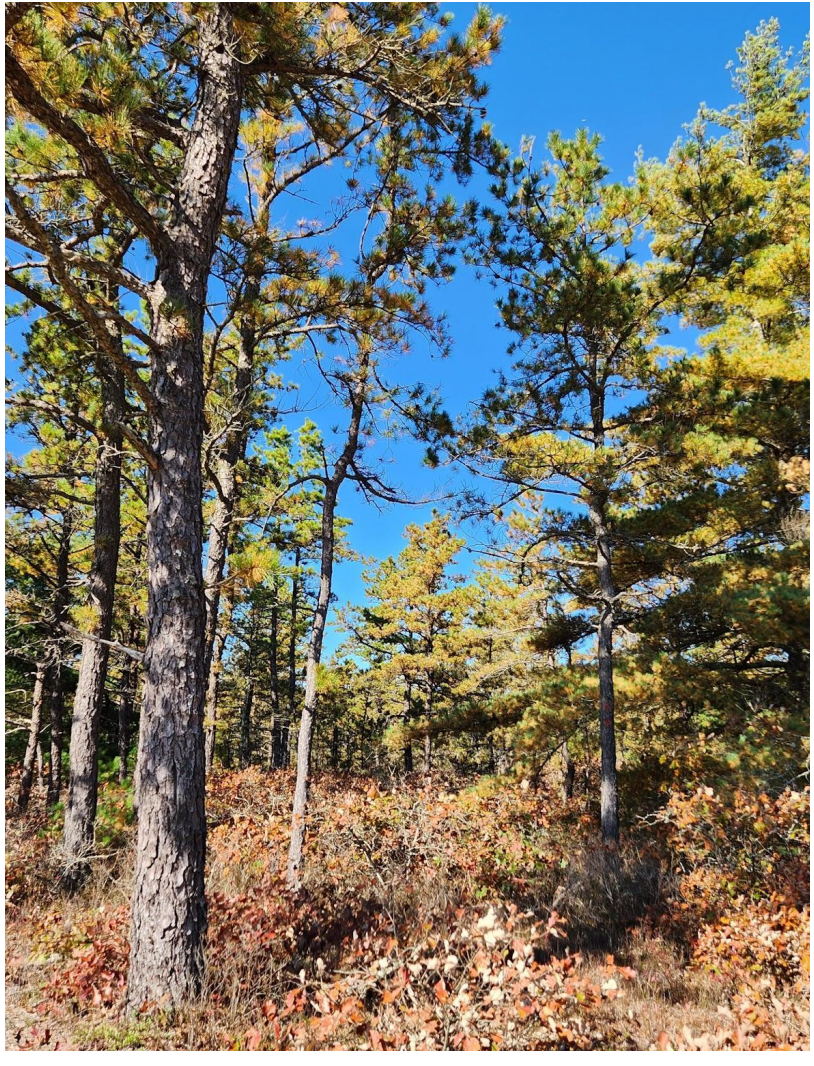
Mount Grace has concerns with an either-or recommendation from the CFC panel that places more emphasis on old forest habitat outcomes at the expense of young forest outcomes. Forest age diversity is important to forest ecosystem functionality, biodiversity, and climate solutions. We can work toward all these outcomes across landscapes. Biodiversity, forest age diversity, ecosystem resilience and climate solutions don't have to be at odds. We can manage for all these outcomes across landscapes. We strongly support the need for flexibility and agency empowerment as we collectively seek to achieve and reconcile multiple goals.

US Forest Service Forest 2019 Inventory Analysis Data for Massachusetts https://www.fs.usda.gov/research/treesearch/60977 indicates that young forests comprise only 0.4% of forest cover by acreage across Massachusetts' 2,984,347 acres of forestland. There are 570 Species of Greatest Conservation Need identified in the Massachusetts State Wildlife Action Plan, and declining forest age class and species diversity is a major contributing factor. While grassland and shrublands are often lumped into the young forest category, these are complimentary but distinct biodiversity features.

Mount Grace stands together with conservation partners for the future of Massachusetts' forests as climate solutions, and to advance biodiversity, resilient forests, thriving communities and places of respite that provide us all with so many co-benefits.

Thank you,

Emma G Ellsworth
Executive Director
Mount Grace Land Conservation Trust



A Visual Report on DCR's implementation of their 10-Year "Forest Restoration" Plan for the Myles Standish Complex located in Carver, Plymouth, & Wareham, MA

Myles Standish State Forest
FIELD TRIP REPORT

By Glen Ayers • Oct 28, 2023
glenayers@gmail.com

-2000 Acres of Existing Wild Habitat was Eliminated.
-A Diverse Recovering Forest was Simplified & Homogenized.
-No MEPA Process, No Public Say.
-No Climate Impact was Analyzed or Disclosed. MGL Ch. 30, sec. 61

-95% Tree Cover Removal in a DCR "Reserve" where All Logging was Supposed to be Prohibited.
-Local Environmental Groups Were Intentionally Mislead and Lied To.
-All Based on the Agency's Abuse of Discretion.

DCR Utilized the MEPA Loophole-

- MEPA Logging Loophole at 301 CMR 11.03(1)(a)1: Threshold (exemption) applies as long as DCR is following **"an approved forest cutting plan or similar generally accepted practice"** -Whatever that means??? Accepted by Whom?
- No Standard of Review, No Formal Process, No Written Decision, therefore No Appeal is Possible.
- 100% Discretionary and up to DCR to do whatever it wants.

The MEPA Loophole-

- Must be Eliminated so that All State-Owned Forests are Subject to the Full MEPA Review Process.
- Forest Management Planning Must be Required to Follow Existing State Law- MGL Chapter 21, section 2F (Resource Management Plans)

Utilized the DCR "Reserves" Loophole-

From page 22 of the Landscape Designations for DCR Parks & Forests: Selection Criteria and Management Guidelines (2012) "**Habitat manipulation, silvicultural treatments and commercial harvesting operations are not permitted in Reserves. However, if deemed appropriate by DCR and reviewed by the FRSAC, the following exceptions may be allowed:**

a) Implementation of NHESP recommendations to restore, maintain or enhance habitat for rare and endangered species and exemplary natural or rare communities."

The DCR “FRSAC*” Loophole-

- Based on the DCR-Written Management Guidelines (2012) -Which Are Not Legitimately Promulgated Regulations.
- This DCR-Created Loophole Makes the Reserves Designation Meaningless by Providing Abundant Opportunity for Agency Abuse of Discretion.
- Thousands of Acres of Mature Forests in Reserves are Being Logged by DCR via the FRSAC process.

*Forest Reserves Science Advisory Committee

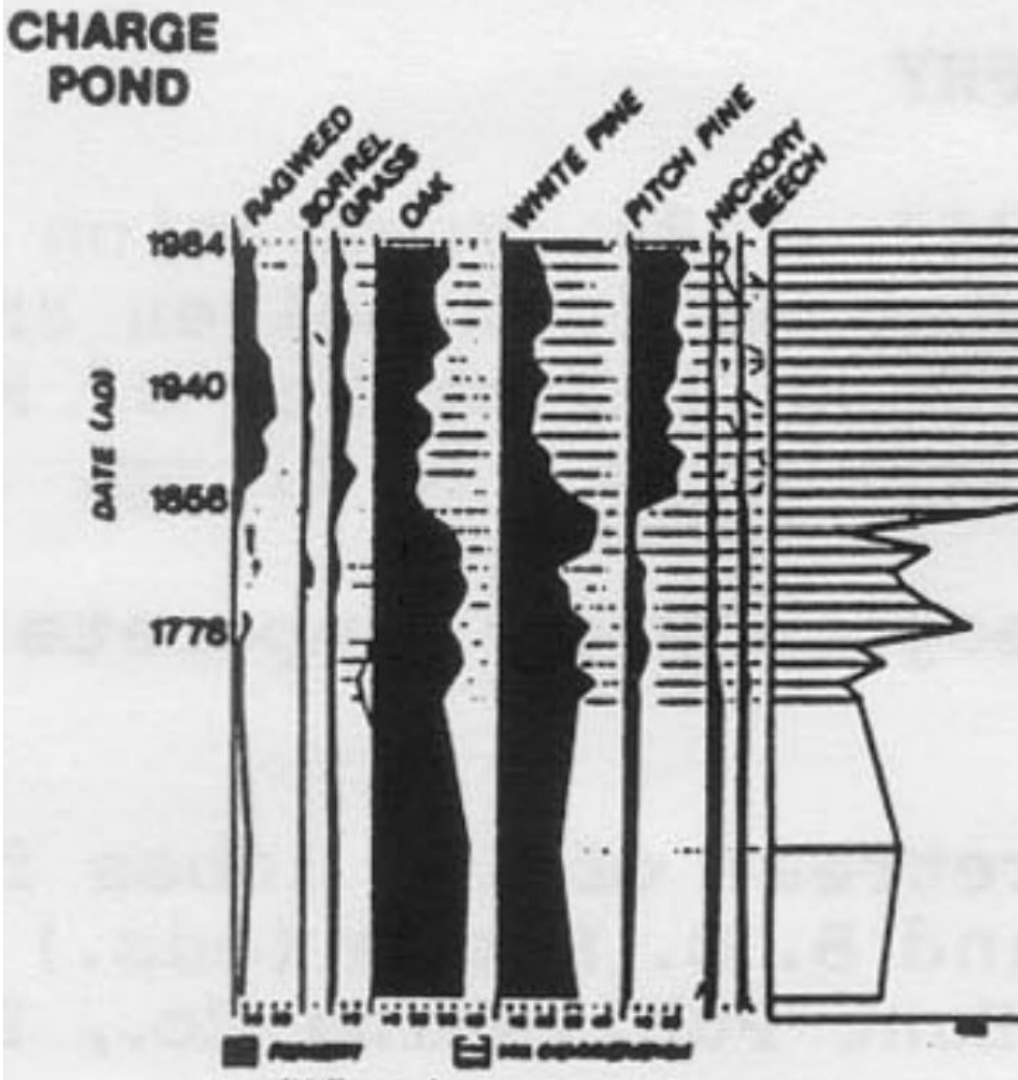
The DCR Approved Logging Plan is Based on Scientific Fraud and 1950's Ecology

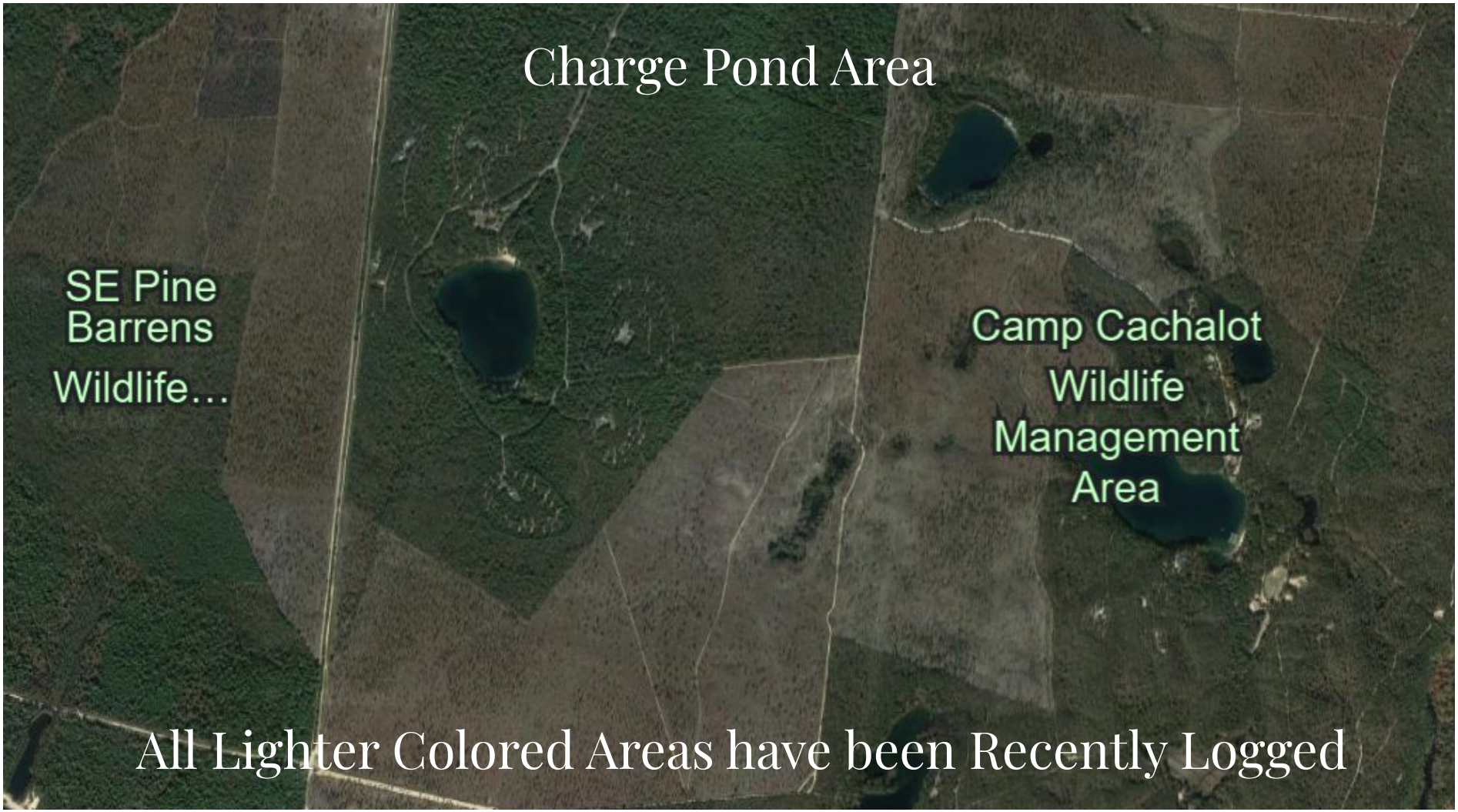
Claiming to be a "Forest Restoration" Logging Project to Create a So-Called "Pine Barrens" Where Historically One Never Even Existed, According to Documented Scientific Evidence.

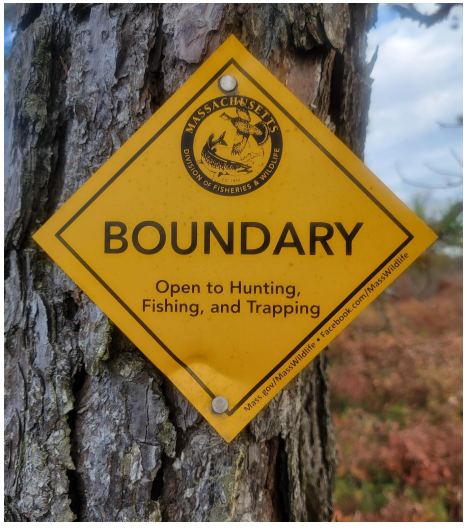
Existing, Unfavorable Science was Ignored

Reconstructed Forest Composition History Based on Tree Pollen in Sediments From Charge Pond Show that this Area was Never a Pine Barrens.

See [Miles Standish Forest from Ice Age to Present]




Charge Pond Area
SE Pine Barrens Wildlife…
Camp Cachalot Wildlife Management Area
All Lighter Colored Areas have been Recently Logged



Creation of a wholly artificial landscape that will require perpetual, intensive maintenance to hold natural succession at bay. FOREVER.

Click Here for Google Map Location

Before and After


“This is Insanity”- Linda Coombs, Aquinnah Wampanoag Elder

-Intentionally Converting the Entire Landscape from an Accelerating Carbon Sink to a Perpetual Source of CO_2 Emissions for Decades to come (or Permanently if their proposed “Management” Plan is Followed).
-Ignoring the Climate Emergency.


The Solution is the Passage of H.4150 to Save Mass Forests

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ARTICLE

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Carbon storage in US wetlands

A.M. Nahlik[1,†,*] & M.S. Fennessy[1,*]

Wetland soils contain some of the highest stores of soil carbon in the biosphere. However, there is little understanding of the quantity and distribution of carbon stored in our remaining wetlands or of the potential effects of human disturbance on these stocks. Here we use field data from the 2011 National Wetland Condition Assessment to provide unbiased estimates of soil carbon stocks for wetlands at regional and national scales. We find that wetlands in the conterminous United States store a total of 11.52 PgC, much of which is within soils deeper than 30 cm. Freshwater inland wetlands, in part due to their substantial areal extent, hold nearly ten-fold more carbon than tidal saltwater sites—indicating their importance in regional carbon storage. Our data suggest a possible relationship between carbon stocks and anthropogenic disturbance. These data highlight the need to protect wetlands to mitigate the risk of avoidable contributions to climate change.

[1] Department of Biology, Kenyon College, 202 N College Road, Gambier, Ohio 43022, USA. † Present address: US Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Laboratory, Western Ecology Division, 200 SW 35th Street, Corvallis, Oregon 97333, USA. * These authors contributed equally to this work. Correspondence and requests for materials should be addressed to A.M.N. (email: nahlik.amanda@epa.gov) or to M.S.F. (email: fennessym@kenyon.edu).

Soil carbon is vital in regulating climate, water supplies and biodiversity—all essential contributions to the provision of ecosystem services[1]. Wetlands contain a disproportionate amount of the earth's total soil carbon; holding between 20 and 30% of the estimated 1,500 Pg of global soil carbon[2] despite occupying 5–8% of its land surface[3]. The anoxic conditions characteristic of wetland soils slow decomposition and lead to the accumulation of organic matter. As a result, wetlands can accumulate large carbon stores, making them an important sink for atmospheric carbon dioxide and holding up to or, in some cases, even more than 40% soil carbon[4], which is substantially greater than the 0.5–2% carbon commonly found in agricultural soils[5]. In the United States, more than half of the historical wetland area has been lost due to anthropogenic activities[6] resulting in a net transfer of carbon from the soil to the atmosphere[7]. This is particularly true for freshwater inland wetlands that make up most of the wetland area comprising, for example, 95% of all wetlands in the conterminous United States[8,9]. Many studies have focused on quantifying the carbon held in terrestrial ecosystems (so-called green carbon) and, more recently, on the carbon held in tidal saline ecosystems, often referred to as blue carbon[10–12]; however, our knowledge of carbon stored in inland freshwater wetlands, which we refer to here as teal carbon, is often overlooked or limited to site-specific studies. Accurate carbon accounting in wetlands is vital to reduce the risk of climate change contributions by identifying and protecting wetlands or wetland-dominated landscapes that hold disproportionately large carbon stocks, and to allow the inclusion of wetlands in carbon-offset programs, such as the United Nation's programme Reducing Emissions from Deforestation and Forest Degradation (UN-REDD +)[13].

Here we provide a quantitative, robust estimate of wetland carbon storage in the conterminous United States as a function of soil depth, landscape position (inland versus tidal saline (that is, coastal)), and region, and an indication of how these stocks may be impacted by anthropogenic stressors using data from the US Environmental Protection Agency's (USEPA) 2011 National Wetland Condition Assessment (NWCA)[14]. These data provide empirical, unbiased, population-level estimates of soil carbon stocks with known confidence limits for targeted populations of wetlands at the national scale, and are not compiled based on the assumptions of a review of multiple sources, as earlier estimates have been (for example, ref. 8). We find that wetlands in the conterminous United States store a total of 11.52 PgC. Much of this carbon is stored within soil layers deeper than 30 cm and in freshwater inland wetlands—particularly those in the Midwest where wetlands with deep organic soils commonly occur in the northern tier states. Our data show that freshwater inland wetlands hold nearly 10-fold more carbon than the tidal saltwater sites that were assessed, in part due to the extensive area of inland wetlands compared with coastal sites—indicating their importance in regional carbon storage. Although we are unable to determine causality, our data also show that carbon stocks are significantly lower at wetland sites with most anthropogenic disturbance compared with sites with intermediate or least disturbance.

Results

National carbon stocks. To quantify carbon stocks (PgC), soil organic carbon concentration and bulk density data were collected by horizon from 120 cm-deep soil pits at 967 wetland sites across the conterminous United States (Fig. 1). Sites were selected from broadly defined NWCA Wetland Types (Table 1) using a stratified-random, probabilistic sampling design[15,16] (the Generalized Random Tessellation Stratified survey[17]). These sites, known as the inference population, represent 25 million hectares of wetlands in the conterminous United States and store a total of 7.54 ± 0.59 PgC (Table 2). The survey design, however, targeted a total of 38.4 million hectares, 13.4 million hectares of which (or 35%) could not be directly sampled primarily due to logistical difficulties[16]. Extrapolating to this full target population requires the assumption that the unsampled area follows the same trends as the sampled area. Accepting this assumption and scaling the estimate to the full 38.4 million hectares of this target population, we estimate that these wetlands store 11.52 PgC (Table 2), or close to 1% of the world's total soil organic carbon[2].

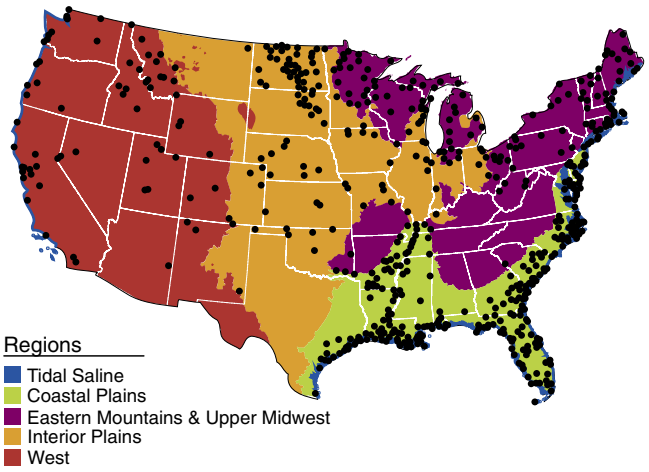

Figure 1 | Map of the distribution of wetland probability sites. Sites (black points) were sampled as part of the US Environmental Protection Agency's 2011 National Wetland Condition Assessment (NWCA) and were analysed by five regions, Tidal Saline (blue area), Coastal Plains (green area), Eastern Mountains and Upper Midwest (purple area), Interior Plains (orange area) and West (red area).

Geographic patterns in carbon stocks. Carbon density (tC ha^{-1}) and stocks varied as a function of location and wetland type (Fig. 2), which are intrinsically linked[18]. When grouped by region, carbon densities reflect a high degree of variability, ranging from 195 to 478 tC ha^{-1} (Fig. 3a). Wetlands of the Eastern Mountains and Upper Midwest store the most carbon, averaging 478 ± 58 tC ha^{-1} and accounting for nearly half of the wetland carbon in the United States (Table 2). This is consistent with the abundance of wetlands with deep organic soils in the northern tier states where characteristic cool temperatures provide climatic conditions that can promote carbon accumulation. Of the 95 freshwater inland sites sampled with predominantly organic soils—designated as such if field descriptions of soil layers indicated that histosols were present[19]—half (47 sites) occurred in the Eastern Mountains and Upper Midwest region, storing an average of 539 ± 47 tC ha^{-1} in the top 100 cm of soil—a conservative estimate given that many organic soil and peat deposits are > 1 m deep[4]. The smallest wetland carbon pools were found in the Interior Plains (195 ± 25 tC ha^{-1}), where hydrologic modification and agricultural disturbance are extensive, contributing to wetland loss and degradation[20] and effectively reducing soil organic carbon[21]. The Coastal Plains and West, where warm mean temperatures and low precipitation lead to more frequent dry downs[22] and slower carbon sequestration rates, hold 198 ± 21 and 216 ± 30 tC ha^{-1}, respectively. In all regions, the greatest carbon densities were found in the top 30 cm of the soil profile (Fig. 3a, Table 2). However, soil layers below

Table 1 | Wetland types and descriptions sampled as part of the 2011 National Wetland Condition Assessment.

NWCA wetland types	Based on	
	S&T categories	Description of wetlands included in NWCA
EH—estuarine emergent	E2EM—estuarine intertidal emergent	Estuarine (E) intertidal emergent (that is, herbaceous = H) wetlands
EW—estuarine woody	E2SS—estuarine intertidal forest/shrub	Estuarine (E) intertidal forested and shrub (that is, woody = W) wetlands
PRL-EM—palustrine, riverine and lacustrine emergent	PEM—palustrine emergent	Emergent (EM) wetlands in palustrine, shallow riverine or shallow lacustrine littoral (PRL) settings
PRL-SS—palustrine, riverine and lacustrine shrub	PSS—palustrine shrub	Shrub-dominated (SS) wetlands in palustrine, shallow riverine or shallow lacustrine littoral (PRL) settings
PRL-FO—palustrine, riverine and lacustrine forested	PFO—palustrine forested	Forested (FO) wetlands in palustrine, shallow riverine or shallow lacustrine littoral (PRL) settings
PRL-f—palustrine, riverine and lacustrine farmed	Pf—palustrine farmed	Farmed (f) wetlands in palustrine, shallow riverine or shallow lacustrine littoral (PRL) settings; only includes a subset that is not currently in crop production
PRL-UBAB—palustrine, riverine and lacustrine unconsolidated bottom and aquatic bed	PUBPAB—palustrine unconsolidated bottom/aquatic bed	Open-water ponds and aquatic bed (UBAB) wetlands in palustrine, shallow riverine or shallow lacustrine littoral (PRL) settings

National Wetland Condition Assessment (NWCA) Wetland Types are cross-referenced with US Fish and Wildlife Service Status and Trends (S&T) Categories[9,16] on which they are based.

Table 2 | Estimated carbon stocks to a depth of 120 cm.

	0–30 cm	31–60 cm	61–90 cm	91–120 cm	Sum 0–120 cm	Area (10^6 ha)
PgC stored by depth increment for the inference population						
Conterminous United States	2.63 ± 0.12	2.08 ± 0.15	1.76 ± 0.19	1.08 ± 0.12	7.54 ± 0.59	25.2
Region						
Tidal Saline	0.20 ± 0.03	0.17 ± 0.03	0.18 ± 0.06	0.20 ± 0.09	0.76 ± 0.21	2.2
Coastal Plains	0.83 ± 0.05	0.56 ± 0.05	0.38 ± 0.06	0.28 ± 0.06	2.05 ± 0.21	10.4
E. Mts & Upper Midw	1.24 ± 0.10	1.09 ± 0.13	0.98 ± 0.15	0.55 ± 0.09	3.86 ± 0.47	8.1
Interior Plains	0.27 ± 0.02	0.17 ± 0.03	0.10 ± 0.02	0.07 ± 0.02	0.60 ± 0.08	3.1
West	0.08 ± 0.01	0.07 ± 0.01	0.08 ± 0.01	0.07 ± 0.01	0.30 ± 0.04	1.4
Carbon type						
Blue (tidal saline)	0.20 ± 0.03	0.17 ± 0.03	0.18 ± 0.06	0.20 ± 0.09	0.76 ± 0.21	2.2
Teal (all others)	2.42 ± 0.12	1.91 ± 0.15	1.59 ± 0.18	0.93 ± 0.11	6.85 ± 0.55	23.0
Disturbance category						
Least disturbed	0.70 ± 0.04	0.58 ± 0.06	0.49 ± 0.07	0.48 ± 0.11	2.25 ± 0.28	5.5
Intermediate disturbed	1.29 ± 0.09	1.04 ± 0.11	0.90 ± 0.13	0.52 ± 0.09	3.75 ± 0.42	12.7
Most disturbed	0.64 ± 0.09	0.47 ± 0.10	0.37 ± 0.12	0.15 ± 0.02	1.63 ± 0.33	7.0
PgC stored by depth increment for the target population						
Conterminous United States	4.02	3.17	2.68	1.64	11.52	38.4
Region						
Tidal Saline	0.20	0.20	0.22	0.25	0.87	2.7
Coastal Plains	1.37	0.92	0.64	0.47	3.39	17.1
E. Mts & Upper Midw	1.53	1.35	1.22	0.68	4.78	10.0
Interior Plains	0.27	0.26	0.16	0.11	0.80	5.0
West	0.08	0.19	0.19	0.19	0.66	3.6
Carbon type						
Blue (tidal saline)	0.20	0.20	0.22	0.25	0.87	2.7
Teal (all others)	3.25	2.72	2.21	1.45	9.63	35.7

E. Mts & Upper Midw, Eastern Mountains and Upper Midwest.
Carbon stock estimates (PgC) for geographic regions, carbon type and disturbance category are provided for (a) the inference population and (b) the target population. Wetland area represented by each group is provided in 10^6 ha. Means are presented with s.e.m. for the inference population. Means for disturbance category s.e.m. for all values are not presented for the target population data because they cannot be calculated for the wetland area not able to be sampled.

30 cm deep contain substantial cumulative reservoirs of carbon, with 65% of the total wetland soil carbon stored between 30 and 120 cm.

Comparison of blue and teal carbon stocks. While recent work has focused on the power of salt marshes and mangroves (tidal saline wetlands) to accumulate blue carbon, less attention has been given to inland wetlands (teal carbon). Differences in carbon densities between saline and inland sites were surprisingly small, with the greatest difference between 91 and 120 cm, where tidal saline sites held more than twice as much carbon as freshwater sites on an areal basis (92 ± 40 versus 41 ± 5 tC ha^{-1}; Fig. 3b). Carbon distribution was also more uniform with depth in the tidal saline sites, with about 25% of the total carbon pool in each of the four depth increments. Carbon densities in the inland sites decreased steadily with depth, from 35.3% of the total carbon in the top 30 cm to 13.6% between 91 and 120 cm. Although rates of carbon accretion cannot be inferred from these data, the smaller

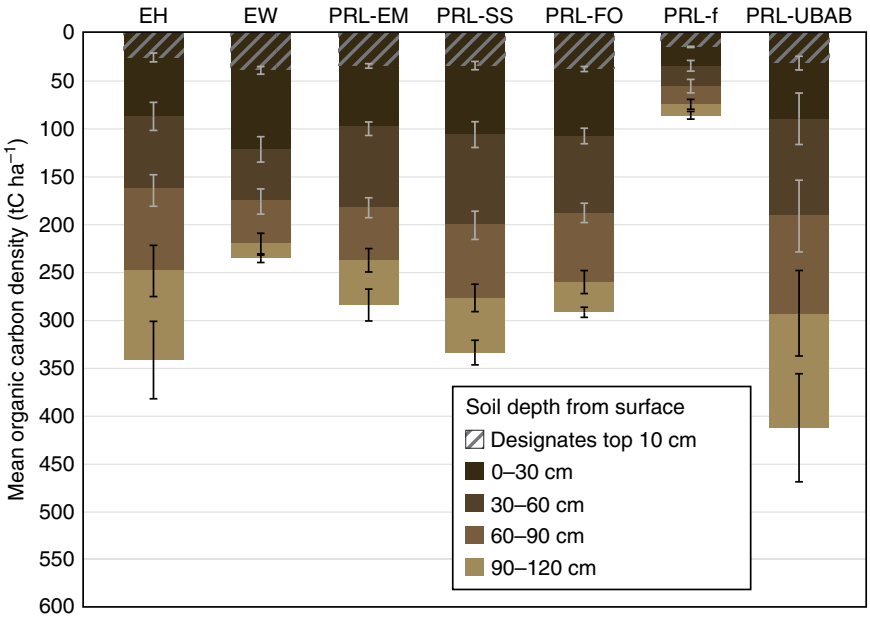

Figure 2 | Mean soil organic carbon density to a depth of 120 cm by National Wetland Condition Assessment Wetland Type for wetlands of the conterminous United States. Carbon densities are reported as tC ha^{-1}. National Wetland Condition Assessment (NWCA) Wetland Types include estuarine emergent (EH), estuarine woody (EW), palustrine, riverine and lacustrine emergent (PRL-EM), palustrine, riverine and lacustrine shrub (PRL-SS), palustrine, riverine and lacustrine forested (PRL-FO), palustrine, riverine and lacustrine farmed (PRL-f), palustrine, riverine and lacustrine unconsolidated bottom and aquatic bed (PRL-UBAB). The grey hatch within the bars represents the top 10 cm of the soil profile (within the 0–30 cm depth increment), followed by progressively lighter shading to represent 0–30, 30–60, 60–90 and 90–120 cm soil depths from the surface. Error bars (both white and black) represent s.e.m. Numerical values for this figure are presented in Supplementary Table 5.

differences in the shallow soil layers compared with deeper layers in the tidal sites may be a result of insufficient time to compound the effects of annual differences in carbon accretion rates in the shallow soil layers. Unlike many inland wetlands, the on-going delivery of sediment and allochthonous carbon in tidal systems leads to sediment deposition, the burial of organic matter, and the vertical accretion of marsh surfaces, countering sediment compaction and subsidence that occurs deeper in the soil profile thus allowing carbon to accumulate over long time periods[12]. Increasing rates of sea level rise can also contribute to soil accretion in salt marshes by increasing the duration of tidal inundation and increasing sediment deposition on marsh surfaces[23]. Despite this, there is nearly 12 times the amount of estimated teal carbon as there is blue carbon in the conterminous United States due to the sheer area of inland wetlands (91% of total wetland area) compared with tidal sites (Table 2). It should be noted that our estimate does not account for the blue carbon held in subaqueous soil systems such as seagrass beds, which occur at water depths not sampled in this study; the inclusion of seagrass beds and their carbon stores would increase our estimate of blue carbon. Although estimates of the amount of carbon in US seagrass beds are lacking, the global average soil carbon stock reported for seagrasses (140 tC ha^{-1}) is substantially lower than those for mangrove (471 tC ha^{-1}) or salt marsh ecosystems (340 tC ha^{-1})[24], which were included in our estimates and whose values are similar to what we report for tidal saline wetlands (340 tC ha^{-1}). In this study, tidal sites overall account for 9% of the wetland area sampled and hold about 8% of the wetland carbon in the United States, illustrating the power of freshwater, inland wetlands to store carbon.

Relationship between disturbance and carbon storage. To assess the impact of anthropogenic disturbance on soil carbon, the NWCA categorized sites as least, intermediately, or most disturbed using *a priori* defined indicators of physical, chemical and biological stressors that were observable at the time of the site visit, either in the wetland area assessed or the 100 m radius buffer area surrounding it (Table 3)[15,16]. The selected stressor indicators have a strong association with anthropogenic impacts and included several related to hydrologic alteration (such as the presence of ditches, dikes, or levees), or the occurrence of agricultural or urban land cover in the buffer area. Least disturbed sites, defined as those with the best available physical, chemical and biological condition given the current status of the landscape[25], were those with few or no observed stressors. They had significantly higher soil carbon stocks (407 ± 51 tC ha^{-1}) than the most disturbed sites (236 ± 47 tC ha^{-1}; Fig. 3c). We lack information to determine whether humans have historically avoided developing the wettest sites with potentially higher overall carbon stores. If so, this pattern of human settlement might predispose least disturbed sites to have greater carbon densities. However, there is also historical evidence that even large deepwater wetlands with high carbon soils were effectively drained early in the history of US agricultural development, such as the Great Black Swamp in northwestern Ohio that covered 4,000 km^2 with water levels up to 1-m deep (ref. 3). Despite this uncertainty in the pattern of anthropogenic disturbance, the mean difference of 171 tC ha^{-1} between least and most disturbed sites may represent a conservative estimate of carbon losses from human activities, as it is probable that even least disturbed sites have sustained some level of anthropogenic influence (for example, beyond the sampling site, such as in the greater wetland area or watershed) that could alter soil composition. For example, agricultural land use and the presence of tile drains in the drainage basins of the US Corn Belt region are shown to increase both stream and base flows, thereby increasing the annual discharge from that drainage basin[26]. This can lead to lower (that is, drier) regional groundwater levels that, over time, could increase soil carbon oxidation and affect soil carbon stores—even in wetland sites that lack directly observable stressors.

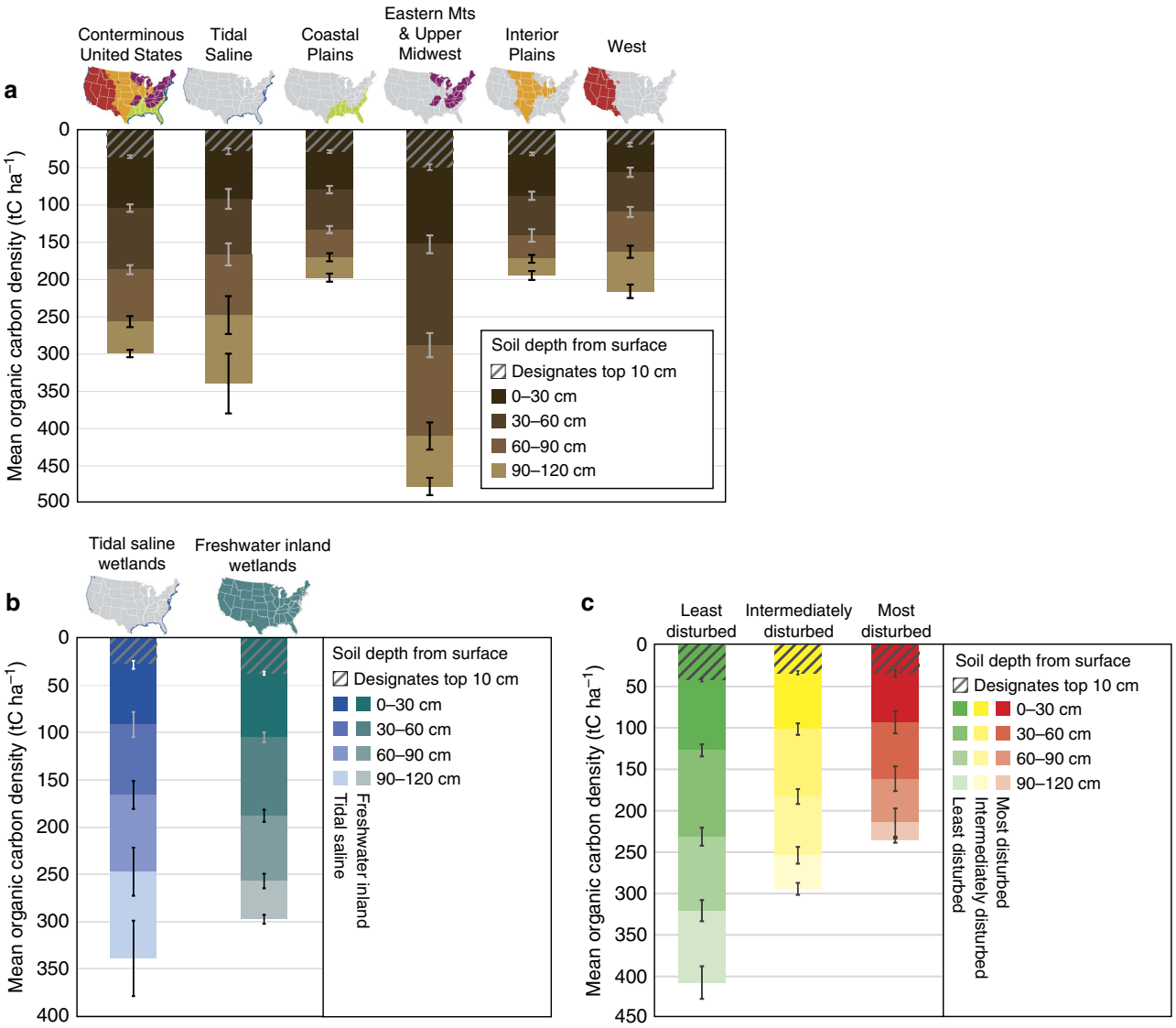

Figure 3 | Mean soil organic carbon density to a depth of 120 cm for different subpopulations. Carbon densities (tC ha^{-1}) are shown for (**a**) the nation and in five regions, (**b**) tidal saline wetlands (blue) and freshwater inland (teal) wetlands and (**c**) least (green), intermediately (yellow) and most disturbed (red) wetlands. Wetland geographic regions include Tidal Saline (TS; coastal and estuarine), Coastal Plains (CPL), Eastern Mountains and Upper Midwest (EMU), Interior Plains (IPL) and West (W). The grey hatch within the bars represents the top 10 cm of the soil profile (within the 0–30 cm depth increment), followed by progressively lighter shading to represent 0–30, 30–60, 60–90 and 90–120 cm soil depths from the surface. Note the data shown in **b**,**c** are calculated using the data shown in **a**. For 0–10, 0–30, 30–60, 60–90 and 90–120 cm, respectively, the number of samples (n) for each subpopulation (identified in subscript after the n) were as follows: $n_{national} = 856$, 853, 785, 590 and 435, $n_{ts} = 282$, 282, 270, 191 and 127, $n_{cpl} = 212$, 211, 181, 139 and 110, $n_{emu} = 137$, 135, 125, 99 and 71, $n_{ipl} = 109$, 109, 97, 71 and 57 and $n_{w} = 116$, 116, 112, 90 and 70. For tidal saline wetlands, $n = 282$, 282, 270, 191 and 127 and for freshwater inland wetlands, $n = 574$, 571, 515, 399 and 308, for 0–10, 0–30, 30–60, 60–90 and 90–120 cm, respectively. $n_{least\ disturbed} = 173$, 172, 164, 105 and 69, $n_{intermediately\ disturbed} = 404$, 404, 363, 278 and 193 and $n_{most\ disturbed} = 279$, 277, 258, 207 and 173 for 0–10, 0–30, 30–60, 60–90 and 90–120 cm, respectively. Error bars (both white and black) represent s.e.m. Numerical values for this figure are presented in Supplementary Table 5.

Although the mechanisms are not well understood, the deepest soil layers sampled (90–120 cm) had the greatest differences in soil carbon with 87 ± 20, 40 ± 7 and 22 ± 3 tC ha^{-1} in least, intermediately and most disturbed wetlands, respectively (noting that the bulk density of 70% of the samples below 75 cm were estimated using a general boosted model with an R^2 of 0.83 (see Methods)). The loss of carbon from deep in the soil profile may indicate that human impacts are not limited to surface and near-surface soil horizons, or it may be an artefact of the pattern of human settlement on the landscape, in which the wettest sites that tend to contain high levels of soil carbon were preferentially avoided. While anthropogenic disturbance has been reported to reduce carbon stocks to depths of a metre or more in tidal systems[27], there are few corresponding data for freshwater wetlands. The pattern shown here indicating that human impacts may decrease carbon stocks across all wetland classes at the national scale will require further investigation.

Discussion

Our study provides three important insights into wetland carbon dynamics and linkages to climate policy. First, our estimates of regional carbon stocks and carbon density are the only estimates based on unbiased, large-scale regional sampling that are

Table 3 | Measures of disturbance used to define the disturbance gradient.

Measure of disturbance	Data type	Index description
Agriculture disturbances	Buffer	Number of proximity-weighted* observed agriculture disturbances within the buffer, including pasture/hay, row crops, irrigation, confined animal feeding operations and so on
Residential and urban disturbances	Buffer	Number of proximity-weighted observed residential and urban disturbances within the buffer, including roads, parking lots, golf courses, housing, trash, landfill, dumping and so on
Hydrologic disturbances	Buffer	Number of proximity-weighted observed hydrologic disturbances within the buffer, including ditching, dikes and dams, water level control structures, excavation, fill, riprap and so on
Industrial disturbances	Buffer	Number of proximity-weighted observed industrial disturbances within the buffer, including oil drilling, gas wells, mines (surface or underground) and military operations
Habitat modifications	Buffer	Number of proximity-weighted observed habitat modifications within the buffer, including clear cuts, tree plantations, mowing, highly grazed grasses, soil compaction, recent burning and so on
Buffer summary	Buffer	The summary of threshold scores from the buffer indices (agriculture, residential/urban, hydrologic, industrial, habitat)
High impact hydrologic disturbances	Hydrology	Number of observed high impact hydrologic disturbances within the AA, including damming features, impervious surfaces, pumps, pipes, culverts and so on
Moderate impact hydrologic disturbances	Hydrology	Number of observed moderate impact hydrologic disturbances within the AA, including shallow channels, animal trampling, vehicle ruts and so on
Soil heavy metal index	Soil Metal Content	Sum of the number of heavy metal concentrations (Ag, Cd, Co, Cr, Cu, Ni, Pb, Sb, Sn, V, W, Zn) measured in the uppermost horizon above published thresholds
Relative cover of alien plant species	Vegetation	Calculated percentage of relative cover of alien plant species† in the AA, measured within five 100 m^2 plots

Modified from US Environmental Protection Agency's, 2011 National Wetland Condition Assessment Technical Report[16].
*Buffer observations were recorded by proximity to the AA, with observed stressors closest to the AA receiving higher stressor scores than those farthest from the AA.
†Alien plant species are defined as those that are either introduced to the conterminous United States or are adventive to the location of occurrence.

extrapolated to a population of wetlands. Our data provide an important baseline for repeated future surveys, such as the 2016 NWCA, to track spatial and temporal trends in carbon stocks at the population scale. The data we provide here are also necessary to effectively identify characteristics of wetlands or types of wetlands in particular geographic areas that contain disproportionately large and regionally variable carbon stores if we are to implement policies related to climate protection. Interest in establishing markets for carbon credits based on wetland conservation and restoration activities is increasing in the US Federal Agencies, particularly for coastal wetlands[28]. For example, the state of California has initiated a carbon market that includes credits generated for carbon sequestration in wetlands[29]. Although we measured carbon stocks and not sequestration, large-scale wetland studies, such as the NWCA, could serve as an important basis for identifying areas with high-carbon wetlands for inclusion in climate policies. Our data indicate that freshwater inland sites, especially those with high carbon densities, which cumulatively store over 90% of the wetland soil carbon in the conterminous United States (10.67 of the estimated 11.52 PgC in the target population), could be viable candidates when establishing policy to preserve stored carbon that could otherwise, upon wetland drainage or degradation, enter the atmosphere. Wetland areas that seem particularly feasible targets for protecting carbon include the Coastal Plains, which has a regional store of 3.39 PgC, and the Eastern Mountains and Upper Midwest, where wetlands dominated by organic soils alone store 3.52 PgC. By comparison, mineral-soil wetlands for the same region store 1.21 PgC, and all tidal saline wetlands (mineral- and organic-soil combined) store 0.87 PgC (Table 2).

Secondly, we measure and account for deep carbon in this study. Limiting carbon stock estimates to the upper soil profile (for example, 0–30 cm) vastly underestimates wetland storage. Hansen and Nestlerode[30] reflect this in their study where they report soil carbon densities to a depth of 10–15 cm in the Gulf of Mexico coastal region of 34–47 tC ha^{-1}. Our measurements indicate that coastal carbon estimates may in fact be an order of magnitude greater, 340 ± 94 tC ha^{-1}, by assessing soils to 120 cm. Accounting for the carbon stocks of deeper soil layers more fully represents this ecosystem service that wetlands provide.

Finally, our results suggest that there may be a negative relationship between anthropogenic disturbance and soil carbon, perhaps extending to the deeper soil layers where we tend not to measure. One concern centred on wetlands, particularly freshwater sites, is that they are significant methane sources relative to coastal sites where high sulfate levels keep methane production low[31]. However, focusing on current rates of carbon fluxes overlooks the fact that wetland conversion, degradation and warming can lead to a rapid loss of ancient carbon[12] that forms some of the large carbon pools documented in this study. For example, estimates show that the conversion of peatlands to other land uses could release the equivalent of 175–500 years of methane emissions if that same area were destroyed[32]. Sharp increases in carbon dioxide emissions have been noted in coastal wetlands with ecosystem degradation or conversion, amounting to 0.15–1.02 PgC globally[27]. The studies suggest a mechanistic explanation of how human activities could decrease soil carbon at regional scales, moving carbon from soil to the atmosphere as carbon dioxide and methane. Efforts to protect climate should address the role of wetlands as climate regulators and include measures for the conservation and sustainable management of their carbon stocks.

Methods

Sample frame. During the 2011 growing season (April–September, location dependent), 967 wetland points in the conterminous United States were sampled as part of the NWCA—an effort to evaluate the condition of the wetlands in the United States led by the USEPA with cooperation from state and tribal partners (Fig. 1). The target population was defined as: all wetlands of the conterminous United States not currently in crop production, including tidal and non-tidal wetted areas with rooted vegetation and, when present, shallow, open water <1 m in depth[15]. A probabilistic design was used to select wetland points using the US Fish & Wildlife Service's National Wetland Status & Trends (S&T) sample frame[2,9,33], made up of ~5,000 4-mi^2 plots, and a Generalized Random Tessellation Stratified (GRTS) survey design[17] stratified by state with unequal probability of selection by seven NWCA Wetland Types based on the S&T wetland categories (Table 1). Although S&T estimated wetland extent to be 44.6 million hectares (110.1 million acres) in the conterminous United States[9,33], only a subset of wetlands included in S&T—approximately 38.4 million hectares (94.9 million

acres)—met the NWCA target definition and so were included for sampling. The approximate 6.2 million hectares of wetlands included in S&T but were considered non-target for the NWCA, and therefore excluded from the survey, comprises wetlands that were actively cropped, wetlands used for aquaculture and wetlands that typically lack vegetation or routinely occur in water >1 m deep (for example, estuarine intertidal aquatic bed (E2AB), estuarine intertidal unconsolidated shore (E2US), marine intertidal (M2) and palustrine unconsolidated shore (PUS) S&T wetland categories (with S&T mapping codes followed in parentheses)). Of the 38.4 million hectares of NWCA target wetlands, a further 28% were unable to be sampled in the field due to landowner access denial, physical inaccessibility, size not meeting the minimum criteria, depth exceeding 1 m and so on. Therefore, the sampled wetland population for which we were able to directly extrapolate to (called the inference population) includes 25.1 million hectares (62.2 million acres; Supplementary Fig. 1).

Field sampling. At each wetland point, a 0.5-ha circular assessment area (AA) was established, with no more than 10% of the area in upland or in water over 1 m deep. To meet the establishment criteria, the AA was occasionally adjusted to fit the shape of the wetland or reduced in size (to a minimum of 0.1 ha) if the point fell in a wetland smaller than 0.5 ha. In addition, a buffer area was established using 100-m transects at the cardinal directions of the AA perimeter. During a single-day visit to each wetland point, field crews collected data and samples associated with vegetation, soils, hydrology, water chemistry, algae and buffer according to the NWCA field protocol[15].

Four 60 cm soil pits were excavated within the AA, after which a representative soil pit was established among the four and was expanded to 125 cm deep. At the representative soil pit, soil profiles were described by horizon to 125 cm or the deepest attainable depth. Specifically, soil textures were designated for each horizon, including information used to distinguish mineral soils (for example, sandy, loamy/clayey, mucky mineral) from organic soils (for example, peat, muck, mucky peat). For every horizon greater than 8 cm thick, a set of three hammered cores was collected for bulk density using a closed-top corer of a known volume (typically 6.5 cm in diameter and 4.5 cm in depth, although field crews could use improvised corers as long as the diameter and depth of the device was recorded), and an additional 1.0–2.5 l of soil for chemical analysis was collected. In saturated or inundated soils, special tools and alternate extraction methods were used to collect soil samples. Specifically, coffer dams reinforced with plastic and hand pumps were used to remove standing water from in and around soil pits, and King soil extractors (also known as tube extractors) were used to collect soil samples[15]. Upon collection, soil samples were refrigerated and sent in batches within 2 weeks to the Natural Resources Conservation Service (NRCS) laboratory in Lincoln, Nebraska for analysis. Standard NRCS Soil Survey Laboratory (SSL) procedures[34,35] were used for analysis of sand, silt and clay, carbonate, total carbon, cation exchange capacity (CEC), electrical conductivity (EC) and bulk density (Supplementary Table 1). Soil organic carbon (SOC) was calculated as the difference between total and inorganic carbon. To prepare samples for carbon analysis, soils were air dried, crushed and sieved to <2 mm to obtain the fine earth fraction. Total carbon was measured using an elemental analyzer, and inorganic carbon (that is, calcium carbonate ($CaCO_3$) equivalent) was determined by exposing the soils to hydrochloric acid (HCl) and measuring the evolved carbon dioxide (CO_2) manometrically[34].

Quality assurance and bulk density modelling. Of the 4,061 soil horizons described, ~25% were <8 cm thick and, therefore, were not sampled for analysis. Where soil carbon data from the top horizon were missing, it was equated to the next lower horizon (noting that if the top horizon was organic and the next lower horizon was mineral, the carbon content of the top horizon might be an underestimate, making this estimate conservative). Missing soil carbon from a middle horizon was estimated using the average of the horizon immediately above and below. Furthermore, ~30% of the bulk density data were missing due to difficulties in the field or failed quality assurance. Bulk density for missing horizons and for measured values >2.0 g cm^{-3} (the latter assumed to be in error since 2.0 g cm^{-3} is the upper limit of measurable bulk density) was modelled using a generalized boosted model in the gbm R package[36,37]. Generalized Boosted Regression Modeling is a type of regression model that combines regression trees and boosting algorithms and is a means of predictive modelling by building many regression trees using an independently drawn, random sample, with each new tree using the prediction residuals from all preceding trees. Martin *et al.*[38] showed that the Generalized Boosted Regression Model method produced more accurate and precise estimations of bulk density than a multiple regression, which is more commonly used. In building our model, we optimized the parameters using procedures described by Martin *et al.*[38] and Jalabert *et al.*[39]. Seventy percent of the data were used to train the model. Model variables included (with percent of variability explained) SOC (77.2%), 10 NWCA Reporting Groups (4.6%, see the following section for more information on NWCA Reporting Groups), EC (3.7%), CEC (3.1%), horizon depth (2.8%), percent clay (2.2%), percent silt (2.1%), hydrogeomorphic (HGM) class (as determined in the field, 1.9%, ref. 15), percent sand (1.8%) and order of horizon within the profile (0.49%). The quality of the fit of the model (R^2), tested against the remaining 30% of the data not used for model calibration, was 0.83 (Supplementary Fig. 2). Because of difficulties accurately sampling bulk density in the field, any measured values that differed from the modelled bulk density by 40% were replaced with the modelled value.

Sample sizes tended to decrease with horizon depth due to the difficulty extracting samples from deep horizons in the field. Of the 1,287 soil layers 75 cm deep or greater that were described by the field crews, 899 bulk density values were modelled. Most of these values necessitated modelling because the horizon was unable to be collected; only 13 bulk density values were modelled because the percent difference was greater than 40% between measured and modelled values, and 14 bulk density values were removed because they failed quality assurance.

Ultimately, 3,542 soil horizons had complete data on SOC and soil bulk density, which were used to calculate the concentration of stored carbon in each soil horizon using the following equation:

$$\rho_c = \frac{((10,000A)(d_l)(\rho_d))(C)}{100} \quad (1)$$

where, ρ_c is carbon density expressed in g m^{-2}, A is area expressed in cm^2 m^{-2}, d_l is layer depth expressed in cm, ρ_d is bulk density expressed in g cm^{-3} and C is SOC concentration expressed as a percent.

Because the depths of soil horizons are not consistent among wetland soils, the quantity of stored carbon was calculated by dividing each horizon into 1 cm increments to allow us to report wetland carbon stocks within any depth range. We report depth up to 120 cm.

To summarize, sources of error in our analysis are predominantly associated with the fact that of the total 4,961 soil horizons described, ~25% of these were <8 cm thick and, therefore, were not sampled for laboratory analysis. As a result of missing soil chemistry data for some layers, we extrapolated estimates of SOC to layers not measured from adjacent layers that had data. This tends to underestimate carbon content, particularly when the extrapolation was made for the top horizon using the underlying horizon. Second, missing bulk density values were estimated using generalized boosted regression modelling. While the fit of the model was strong ($R^2 = 0.83$), this approach may introduce error, particularly for soil layers below 75 cm where a high proportion of bulk density values were modelled.

Determination of organic and mineral soil carbon density. Carbon density in the top 100 cm of soil was estimated for organic- and mineral-soil dominated wetlands (that had soil carbon and bulk density values for every described layer up to 100 cm deep) located in inland (freshwater) and coastal (tidal saline) settings (Supplementary Table 2) using R statistical computing language[36]. Using the US soil taxonomy of Histosols[19], organic-soil wetlands were designated as such if each horizon up to a minimum of 40 cm was identified in the field as an organic soil (for example, peat, muck or mucky peat), or at least 40 cm of the top 80 cm of soils were identified as organic, or, in the case of the presence of an impenetrable layer within the top 40 cm, two-thirds or more of the total soil thickness was identified as organic with <10 cm of total mineral soil. Mineral-soil wetlands were designated as such if they did not pass the criteria of an organic-soil wetland.

Population estimates and reporting groups. The probabilistic design frame allows sample weights to be assigned to each individual site based on the inverse probability of that point being sampled[40–42] so that results may be expressed as estimates of the entire resource by wetland area of sampled wetlands—25.2 million hectares (Supplementary Table 3, for example, ref. 16). The statistical estimates of mean and total carbon stocks for the national population of target wetlands were completed using the spsurvey R package[36,43].

Ten NWCA Reporting Groups were developed based on a combination of (1) four major ecoregions (based on aggregations of Omernik Level III Ecoregions[44]), which include Coastal Plains (CPL), Eastern Mountains and Upper Midwest (EMU), Interior Plains (IPL) and West (W), and (2) wetland type, which includes estuarine (E) woody (W), estuarine (E) herbaceous (H), inland woody and inland herbaceous). Inland wetlands include palustrine, riverine and lacustrine (PRL) wetlands. Tidal saline wetlands (which include estuaries, high and low tidal marshes, and other coastal (tidal saline) wetlands) are combined for the entire contiguous United States (ALL), therefore, only 10 NWCA Reporting Groups exist[16]—ALL-EW, ALL-EH, EMU-PRLW, EMU-PRLH, CPL-PRLW, CPL-PRLH, IPL-PRLW, IPL-PRLH, W-PRLW and W-PRLH. In this study, the 10 NWCA Reporting Groups are most often combined by vegetation type resulting in five reporting groups (that is, the four ecoregions plus Tidal Saline). It should be noted that the ten NWCA Reporting Groups were defined for reporting purposes after site selection (that is, the survey design) so that each reporting group held a large enough sample size to make data analysis robust.

To address questions of how soil carbon varies regionally, estimates of carbon stocks were made for several subpopulations, including five geographic areas (Tidal Saline, Coastal Plains, Eastern Mountains & Upper Midwest, Interior Plains and West), carbon type (tidal saline blue carbon and freshwater inland teal carbon), and disturbance level (least, intermediate and most disturbed). Note that subpopulations represent the same set of data expressed in different ways.

Disturbance gradient. Only data from the 967 randomly selected probability sites were used to report results in this study. However, an additional 171 non-

probability sites (defined as such because they were not included in the S&T sample frame and instead hand-picked by states or tribes to be sampled) were measured in the field using the standard NWCA field and laboratory protocol at the same time as the probability sites. Field and laboratory data from all 1,138 wetland points, representing both probability and non-probability sites, were used to define a disturbance gradient.

The disturbance gradient was developed by screening sites using variables that have a strong association with anthropogenic impacts. Ultimately, nine disturbance indices and a plant disturbance metric were developed based on observations within the site (that is, the AA and buffer), hydrologic variables, soil trace metal data and the cover of alien plant species[16] (Table 3). For each of these ten measures of disturbance, a disturbance threshold was set and every site was screened to test for exceedance.

Because the extent of human disturbance can vary greatly among regions and wetland types, thresholds were set independently for each of the ten NWCA Reporting Groups (Supplementary Table 4). Initially, if any threshold was exceeded at a site, it was not considered a least disturbed reference site; however, for some thresholds in some NWCA Reporting Groups, there were an insufficient number of sites that did not exceed the thresholds. Specifically, inland herbaceous wetlands located in the Interior Plains (IPL) and West (W) ecoregions had the most relaxed thresholds[16]. When thresholds were relaxed, least disturbed was defined as sites with no or minimally observed human disturbance (as opposed to zero observable human disturbance). Ultimately, the least disturbed reference sites were those that were below the thresholds for all 10 measures.

Sites classified as most disturbed on the disturbance gradient were defined using a filtering process in the same manner as the least disturbed sites. In this case, thresholds were set for each measure to define high levels of disturbance. If any single threshold for any measure was exceeded, the site was considered a most disturbed site. Because most disturbed is a relative definition, ~20–30% of the sites were defined as most disturbed, and thresholds were set accordingly.

Finally, the sites not falling into either least or most disturbed were classified into the intermediate disturbance category. Of 1,138 sites screened, 277 sites (24%) were classified as least disturbed, 530 sites (47%) were intermediately disturbed and 331 sites (29%) were most disturbed.

Note that of the 195 organic-soil wetlands in inland and coastal settings, 62 sites were defined as least disturbed (that is, 22% of all least disturbed sites were dominated by organic soil), 80 sites were intermediately disturbed (that is, 15% of all intermediately disturbed sites were dominated by organic soil) and 53 sites were most disturbed (that is, 16% of all most disturbed sites were dominated by organic soil), suggesting that anthropogenic disturbance may similarly affects carbon-rich, organic-soil wetlands and lower carbon, mineral-soil wetlands.

Data availability. Data (raw data and general results from the 2011 National Wetland Condition Assessment) are publically available from https://www.epa.gov/national-aquatic-resource-surveys/data-national-aquatic-resource-surveys

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Author contributions

A.M.N. and M.S.F. designed this study based on publically available data from the United States Environmental Protection Agency; A.M.N. performed the data analysis and designed the figures with input from M.S.F.; together, A.M.N. and M.S.F. discussed the results and wrote the manuscript.

Additional information

Supplementary Information accompanies this paper at http://www.nature.com/naturecommunications

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From: Colleen Ryan
To: Guidelines (EEA)
Cc: Robert Perschel
Subject: New England Forestry Foundation"s comments on the Climate Forestry Committee Report
Date: Wednesday, January 24, 2024 1:10:39 PM

New England Forestry Foundation (NEFF) commends the Commonwealth of Massachusetts and the Healey-Driscoll Administration for undertaking the ambitious and progressive work of reexamining how we manage our forests in the context of our current understanding of climate change. The Forests as Climate Solutions initiative will bring much needed attention and resources to land conservation and forest stewardship, recognizing the vital role that our forests and forest management play in securing atmospheric carbon domestically.

NEFF was appreciative of the opportunity to participate in the Climate Forestry Committee and offer our research findings and long experience with forest management as an input to the report. We laud the comprehensive approach the Administration has taken, inclusive of efforts to reduce forest loss and expand reserves, create incentives for better forest management on private lands, support local markets for sustainable wood products, and address the data and research needs that will help us understand how to best manage forests with respect to climate change.

We are supportive of the primary messages of the report, namely:

- that good forest management is crucial to addressing climate change,
- that keeping forests as forests is fundamental,
- that forest management decisions should be informed by multiple site-specific factors, including management history and landscape context,
- that forests should be managed for the full array of important services they provide to people and the planet, rather than with an exclusive focus on carbon or climate,
- that active and passive management are both needed to achieve the full array of goals society has for our forests, and
- that *both* increasing climate-smart forestry and an expanded system of forest reserves are important parts of the solution.

We also support the committee's guidance that forest managers should have flexibility to implement the recommendations in the report while applying their professional judgement and expertise with respect for the specific characteristics and context of a given forest. There is no one-size-fits-all approach to forestry.

However, we would also like to share a few concerns. First, while the full report contains thorough analyses of key issues and evidence, the Executive Summary does not always accurately reflect the recommendations in the main body of the report and seems to imply consensus in some areas where there was not clear consensus. For example, the Executive Summary gives the impression that there was agreement among the committee that passive management of forests is best for the climate. This greatly oversimplifies the conclusions in the full report, which call for "a mix of forest management approaches across the landscape

to account for uncertainties in future conditions and ecosystem responses (e.g., degree to which tree species ranges will shift) and to mitigate risks from climate change, such as more frequent and severe disturbances."
In particular, the body of the report acknowledges that there was sharp disagreement within the committee about the relative importance of producing more wood locally in order to reduce emissions from importing wood versus reducing harvest to maintain more carbon in local forests while shifting the forest carbon and environmental impacts of harvesting to other locations. However, this nuance was lost in the Executive Summary.

Readers should be aware that to truly understand the recommendations of the report and the level of consensus or disagreement among the committee, one must read the entire report and not rely on the summary.

Second, it is unclear, particularly in the Executive Summary, whether recommendations and the analysis that supports them are referencing state-owned forests specifically, or all Massachusetts forest land. This is a critical distinction, as management objectives and constraints are often quite different between public and private lands. For example, the somewhat sweeping conclusion against salvage harvesting rests on the concept that there is no ecological basis for salvage harvesting. (The Executive Summary says, "The Committee found no ecological rationale for salvage harvesting…" whereas the full report says, "The Committee found no ecological rationale for salvage harvesting *on public land*.") While state agencies may be guided primarily by ecological goals, many private owners face different constraints. For example, income from a salvage harvest may enable a landowner to maintain their forest as forest. Or private owners may simply prioritize other goals, such as harvesting wood products that can contribute to the bioeconomy and potentially substitute for less sustainable materials. **Because much of the information that supports the recommendations is specific to state-owned forests, policymakers should use caution when applying these recommendations to policy aimed at private lands or all Massachusetts forest lands.**

Third, the report generally does not address the role of forests in mitigating climate change in a holistic, systems-based way. As a result, the big picture is not clear, and the wrong policy conclusions for Massachusetts may be reached. For example, the report states, "The Committee generally agreed that passive management confers greater increases in carbon stocks than active, and that allowing forests to grow and age is typically best to maximize carbon storage." It is unclear whether this statement applies to carbon in the forest, where there would be general agreement on this point, or to overall greenhouse gas outcomes, which would need to include carbon in products, substitution benefits, and the potential for leakage of harvest activities to other locations.

Applying a holistic, systems-based approach important to decisions about our forests is critical. NEFF provided more background on this key matter of perspective and always asking the right question in our original comments. An excerpt is copied below. However, the report

unevenly follows this holistic, systems-based criteria, drifting in and out of the necessary perspective at various points. As a result, it may prove difficult for decision makers to understand when the conclusions in the report apply to the narrow viewpoint of in-forest carbon only.

> *In order to address this question of how to manage our state's public forests we have to ask the right question to begin with. We believe the best question to start the discussion with is:*
> *How can we build resilience and help forests adapt to climate change so that we can optimize the capacity of forests to mitigate climate change and deliver the goods and services valued by the people of Massachusetts?*
>
> *The question you offered at the public session, "How can humans optimize carbon storage and resilience in forests?" is a good one, but it is a subset of the umbrella question phrased above. If we asked this same question about agricultural lands the answer would ultimately be that we should stop farming and let the acres revert to forest. Farmers modify original ecosystems to provide food for our society and foresters modify forests to provide biobased renewable forest products. If we want to think about forests and climate change, we have to think about how we harvest trees - or don't harvest them - within the context of a larger system that encompasses what happens in the forest as well as how our forests interact with human lives and human economies, and how these interactions impact climate change.*

NEFF is also concerned about some specific recommendations in the report, including the reduction of early successional habitat goals. **We feel that wildlife biologists should be the primary source of habitat recommendations and should also decide questions such as whether vegetation created by utility or transportation corridors is suitable to provide for the needs of early successional wildlife species.**

We also have concerns about the recommendation that "agencies be more specific and transparent when developing and proposing management actions by identifying the forest element or characteristic to be made more resilient, the disturbance to be addressed, and the way a proposed action improves the situation." While clear management objectives are important, we know that the changing climate will bring new, as-yet unknown, threats and less predictability, which will make it even more challenging than in the past for managers to identify the specific threats that may affect a given forest. Yet, there is clear scientific consensus to support specific types of active management that can improve forests' ability to adapt to changing climate in a holistic way. For example, there is consensus that variety in age, class, and structure in a forest stand creates a more resilient forest. Asking a land manager to identify and manage specifically for a future forest threat (such as a novel pest or a hurricane) strays away from established scientific method into a realm of speculation. Managers should be free to apply appropriate management to increase resilience even if they can't predict the specific disturbance that may impact a specific location.

Finally, regarding the role of wood production, which, as noted, is a *byproduct* of larger or concurrent management goals on state lands, NEFF agrees with the panel's assessment that calls for

> *…the establishment of a goal to produce a higher percentage of the wood products consumed in Massachusetts within the Commonwealth, while staying well below the rate of forest growth, citing significant emissions associated with importing wood from other regions of the United States and other parts of the world. They argued that given the level of wood consumption in Massachusetts, it is ethically important to produce wood products for local consumption to help address the significant gap between the Commonwealth's wood product use and in-state production.*

NEFF was concerned to read the statement made by a few on the panel that "Massachusetts' forests are better suited for removing and storing carbon, and other forests across the nation and around the world are better suited for producing forest products." This comment does not appear to be substantiated, and opinion should not be included on par with more thoughtful, research-backed contributions. Which regions of the world are more suitable, and what criteria would we use to determine that? Would we want to harvest in forest regions with lower stocking and lower performance criteria or less stable forms of government or different timber types? Even leaving aside equity concerns, we are skeptical of the idea that harvesting in another, unnamed location is likely to have better climate outcomes than producing wood locally. We believe that wood products that continue to store carbon for long periods are integral to achieving climate goals and furthermore that their sustainable production can be combined smartly with other initiatives focused on forest health, resilience, and biodiversity. This type of sustainable wood production can also help us meet societal goals to build affordable housing with less need for materials such as steel and concrete, which lead to greater greenhouse gas emissions.

We appreciate this opportunity to provide comments on the final report, as well as the generally welcoming approach that has been taken to input from subject matter experts and the concerned public throughout this process. We look forward to continued progress on the important goals of the Forests as Climate Solutions Initiative, and we will continue to be available as a resource for the Commonwealth on related issues.

Sincerely,
Robert T. Perschel
Executive Director
New England Forestry Foundation

Submitted on behalf of Robert Perschel and NEFF by
Colleen Ryan (she/her) | Forest Scientist

T 207.370.8408

cryan@newenglandforestry.org
newenglandforestry.org

New England Forestry Foundation
Conserving Forests for Future Generations

NASHUA RIVER WATERSHED ASSOCIATION

Protecting our water, our land, our communities

January 24, 2024

Massachusetts Executive Office of Energy
and Environmental Affairs
Attn: Secretary Tepper
100 Cambridge Street, Suite 1020
Boston, MA 02114

Re: Comments on Climate Forestry Committee: Recommendations for Climate Oriented Forest Management Guidelines

Dear Secretary Tepper:

The Nashua River Watershed Association (NRWA) would like to thank the Healey-Driscoll Administration for undertaking the Forests as Climate Solutions Initiative. We would also like to thank the Climate Forestry Committee (CFC) for their hours of work researching, debating, conducting public listening sessions, and preparing their report.

The NRWA participated in both public listening sessions, and submitted written comments encouraging the Commonwealth to protect forests as forests, to carefully consider state-planned habitat restoration projects involving conversion and destruction, and to seek transparency and public participation for any state-planned projects.

The NRWA has reviewed the *Climate Forestry Committee: Recommendations for Climate Oriented Forest Management Guidelines*. We are particularly pleased to see that these guidelines from the CFC include key points for which we advocated including the following:

1) Keep Forests as Forests "The Committee unanimously agreed that maintaining forest cover is essential." (CFC Report page 27) Loss of forest is loss of carbon storage and sequestration.
2) Forest Management for Habitat The Committee recommended state agencies, especially MassWildlife, reconsider their habitat restoration goals to have less emphasis on creating early successional habitat that requires forest clearing and focus instead on development of habitat with old-growth forest characteristics. (CFC Report page 28-29)
3) Increase Transparency The Committee recommended that the state "increase transparency and public information relative to state forest management activities." (CFC Report page 10)

We understand that this Report provides only guidelines to state agencies including the Division of Fisheries and Wildlife and Department of Conservation and Recreation. We very much look forward to learning how these agencies will implement these guidelines. We hope this brings on a thorough review of their missions, policy priorities, management goals, and existing project plans that were put on hold under the forest cutting moratorium, that has now expired.

It is our sincere hope that these guidelines will bring MassWildlife to reconsider and abandon its oak woodland restoration project proposed for the Squannacook River Wildlife Management Area (WMA), located within the Nashua River watershed.[1] This project is an example of taking mature forest with a multitude of site attributes such as Wild & Scenic and Areas of Critical Environmental Concern designations, and BioMap attributes such as Forest Core, Rare, Endangered and State listed Species Habitat, and Coldwater Fisheries to convert it to a barrens, early successional habitat through extensive forest cutting, herbicide application, and burning. It seems a prime example of the type of project that the CFC is recommending be put aside in order to allow our mature forests to serve in their capacity as climate solutions.

Thank you for this opportunity to provide written comments.

Respectfully submitted,

Jennifer Keegan
NRWA Executive Director

[1] Oak Woodland Restoration at Squannacook River WMA, https://www.mass.gov/info-details/oak-woodland-restoration-at-squannacook-river-wma (last visited Jan. 24, 2024).

Loggers Standing Strong Since 1995
108 Sewall St., P.O. Box 1036
Augusta, ME 04332
Phone: 207.688.8195
Fax: 207.620.7517
plcloggers.org

January 24, 2024

Ms. Stephanie Cooper
Undersecretary for Environment
Executive Office of Energy and Environmental Affairs
100 Cambridge St., 10th Floor
Boston, MA 02114

RE: Climate Forestry Committee Issues Recommendations for Climate-Oriented Forest Management Guidelines

Undersecretary Cooper,

On behalf of the Board of Directors for the Professional Logging Contractors of the Northeast (PLC), please accept these comments concerning the "Climate Forestry Committee's Recommendations for Climate-Oriented Forest Management Guidelines.

The PLC is the voice of independent logging and associated trucking contractors throughout the Northeast. The PLC was formed in 1995 to represent independent timber harvesting and hauling businesses in a rapidly changing forest industry. The PLC started in Maine now represents contractors that operate across the Northeast.

Climate change has put an exorbanant amount of pressure on industries across the country, especially in the Northeast. Logging and forest trucking are one of the industries that have been deeply impacted by climate change with reduced markets, harmful pests, flooding from recent storms, lost operating time and increased costs. However, like the forests in the Northeast, loggers are resilient.

Loggers will need to adapt to changes in climate now and in the future, but continued inconsistency with government regulations will only add insult to injury, adding cost with increased difficulty to adapt. The question is, how far should government regulation go before it puts private industry out of business?

Within the Climate Forestry Committee's report, there were some points the PLC found concerning and they are highlighted below:

1. Within the first key objective of the climate solutions initiatives, "keeping forests intact via permanent conservation," all but eliminates a management plan for a forest. If the forests are to be managed passively, it would minimize the forest's ability to capture future carbon with new growth. As forests get older, they reach a point where it is beneficial to cut the older trees leaving room for younger forest growth to regenerate in their place. The regenerative growth of the forests in the Northeast will capture more carbon in the long run. Even if a mature tree is harvested, if used in the right application, the carbon is stored permanently in long lasting forest products, even after being harvested. Managing the forests with a passive management plan is not the answer and the way the report is written continues to suggest that there will be little done to actively manage the land in the future.

Moreover, on page 29, it states, "Reduce cutting of maturing forests to create early successional habitats to realize species regeneration and habitat goals." This seems counter intuitive and defies science as reduced cutting will not allow regeneration. Thus, it is our sense that very little harvesting will be done on public land, regardless if it makes sense to cut the mature trees down before they are unuseable.

2. Forest land makes up about 56% of Massachusetts and it is one of the most highly forested states in the nation. With repsect to wood production highlighted on Page 7, it is stated by some committee members that Massachuesetts' forests are better suited for removing and storing carbon and those elsewhere should produce wood to meet Massachusetts' needs." This is very short sighted as Massachusetts is one of the largest users for wood and paper products in the Northeast. Depending on others to provide all of your wood product needs not only puts stress on the other forests in New England and other regions, but hurts the loggers in Massachusetts that are capable of harvesting the timber locally.

3. The established moratorium on state lands was unnecessary and put added strain on the logging companies that had contracts to do the work. Many of the contracts that were delayed now have to go through another bidding process extending the work stoppage. Logging contactors have employees and when logging operations are shut down, the employees feel the negative effects of the loss of work that was promised, as do the communities where these employees reside. Going forward, the signed contracts and work should not be delayed for a government working group to come to a consensus.

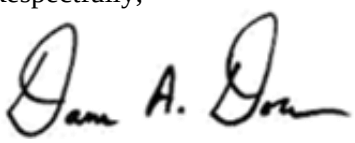
4. It is clear, even with being highly forested, Massachusetts does not come close to producing the amount of wood products that are used in the state. Instead of decreasing the amount of wood harvested on these lands, it would be beneficial to create thoughtful management plans to benefit the forest, the consumer and the climate. Harvesting timber in a way to maximize carbon sequestration, provide much needed wood products to the state and promote climate benefits with healthy forests would be a perfect compromise. The forests are a great natural resource and loggers are stewards of their trade that want to see the forests responsibly harvested to ensure the future of their industry. By not actively managing and harvesting on these lands, it could be detrimental to the forest by making it susceptible to fire, disease, and increased carbon emissions from decaying wood, not to mention the impacts on local economies. By managing public lands, a lot of these risks can be reduced in combination with achieving climate goals set forth by the administration.

5. The innovation of wood heating technology has grown exponentially over the last 10 years. There are plenty of opportunities to reduce carbon emissions from fossil fuels by shifting older oil and natural gas boilers to new, state of the art, modern wood heat appliances. Researching these products and finding the correct applications for them in in state and local projects could be another alternative to help reach Massachussetts' climate goals, utilizing homegrown wood from the state's publicly owned and managed forests.

6. In general, the report was sporadic at times and inconclusive as to what the members of the Climate Forestry Committee agreed upon, leaving consensus anyone's best guess. For a final report there were a lot of items that were left undecided and lacked direction from the committee as there were differing opinions amongst the committee members. It is this indecisiveness which ultimately will harm the state's public forests, one of Massachusetts' greatest assets.

Thank you for your time and consideration of our comments.

Respectfully,



Dana Doran
Executive Director

From: Susan McGinn
To: Guidelines (EEA)
Subject: Prioritize climate health when managing public lands
Date: Wednesday, January 24, 2024 1:47:36 PM

I am a Massachusetts voter and taxpayer and I am writing to comment on the Climate Forestry Committee's Report. My main point is that climate health considerations should be the primary criterion for all forest and tree management decisions on public lands.

I agree with the following points of the CFC Report.
(1) We should follow the climate-based science that all MA public forests should be minimally disturbed, passively managed, and permanently protected from logging so they are allowed to grow and age to maximize carbon sequestration, ecological integrity, soil health, and climate mitigation.
(2) The state should buy more land for permanently protected (no-logging) reserves with a goal of reaching 30% of all MA forests in permanent reserves by 2030 and 50% by 2050.
(3) The state should provide incentives for private landowners to permanently preserve forests and urban trees.
(4) We should follow the climate-based science and prevent logging in watersheds/reservoirs as it can endanger the public water supply.
(5) The state should establish small forested lands in exurban and urban settings as permanently protected reserves.

I disagree with the following points of the CFC Report:
(1) MA public forests should NOT serve any short-term economic goals, for example for the wood industry or the land-trust companies. The majority of MA forests are privately owned; these privately owned forests can serve such economic goals.
(2) The state should NOT log in public forests, especially not in reservoir areas and watersheds.
(3) The state should NOT log for early successional habitat and its associated species. We need to allow our mature forests to reach old-growth stages, where the climate benefits are much greater.
(4) Incentives for private landowners to permanently preserve forests and trees should NOT replace permanent protection of all public forests.

Thank you for your consideration,
Susan

Susan McGinn
soosmcg@gmail.com
(413) 230-6503

From:	Melissa Brown
To:	Guidelines (EEA)
Subject:	Public Comments on the Climate Forestry Committee Report
Date:	Monday, January 22, 2024 12:10:59 PM

I am a member of the Trees as a Public Good Network and a Massachusetts voter and taxpayer and I am writing to comment on the CFC Report. My main point is that climate considerations should be the main criterion for all forest and tree management decisions on public lands.

I agree with the following points of the CFC Report. (1) We should follow the climate-based science that all MA public forests should be minimally disturbed, passively managed, and PERMANENTLY PROTECTED FROM LOGGING so they are allowed to grow and age to maximize carbon sequestration, ecological integrity, soil health, and climate mitigation. (2) The state should buy more land for permanently protected (no-logging) reserves with a goal of reaching 30% of all MA forests in permanent reserves by 2030 and 50% by 2050. (3) The state should provide incentives for private landowners to permanently preserve forests and urban trees. (4) We should follow the climate-based science that we should NOT log in watersheds/reservoirs as it can endanger the public water supply. (5) The state should establish small forested lands in exurban and urban settings as permanently protected reserves.

I disagree with the following points of the CFC Report: (1) MA public forests should NOT serve any economic goals, for example for the wood industry or the land-trust companies. The majority of MA forests are privately owned; these privately owned forests can serve economic goals. (2) The state should NOT log in public forests, especially not in reservoir areas and watersheds. (3) The state should NOT log for early successional habitat and its associated species. We need to allow our mature forests to reach old-growth stages, where the climate benefits are much greater. (4) Incentives for private landowners to permanently preserve forests and trees should NOT replace permanent protection of all public forests.

I urge the state to prioritize the following considerations in implementing the CFC Report: (1) Permanently stop logging on public lands; all projects should be immediately reevaluated for climate (not economic) considerations. (2) Planting trees in urban areas is not sufficient; we need to *preserve* existing urban tree canopy, including making small permanently protected reserves, such as the NEMT Forest (13 acres) and the 4 acres of woods on Morton St. in Dorchester Boston.

Melissa Brown

Protect Newton Trees, Co-Founder
Better Action Now on Artificial Turf in Newton, Co-Founder
Trees as a Public Good Network, Co-Founder & Steering Committee
Our Revolution Massachusetts, GND/Climate Crisis Working Group, Steering Committee

Comments to the "Response to Forest Heritage Planning Process and the STAC Final Report" of February 5, 2013

March 15, 2013

Eric Chivian M.D.
Director, Program on Biodiversity and Human Health
Center for Health and the Global Environment
Harvard School of Public Health

Introduction

I have reviewed the STAC Final Report of November, 2012 and the "Response" document of February, 2013 in great detail, read a large number of scientific articles that bear on the issues raised, and spoken to several scientists with expertise in forest management, forest biodiversity and ecosystem services, carbon sinks, Lyme disease, and other relevant topics.

They include:

Dr. David Foster, Director of the Harvard Forest, Senior Lecturer on Biology, Harvard University
Duncan Stone, Bullard Fellow in Forest Research, Harvard Forest
John Roe, Bullard Fellow in Forest Research, Harvard Forest
Dr. Stuart Pimm, Doris Duke Professor of Conservation Biology, Duke University
Dr. Rick Ostfeld, Disease Ecologist, Cary Institute of Ecosystem Studies
Dr. William Moomaw, Professor of International Environmental Policy, Tufts University, A Lead Author of the IPCC and the Millennium Ecosystem Assessment

While my comments have been informed by these discussions, the views expressed below are mine and mine alone, and do not intend to represent in any way the positions of the Center for Health and the Global Environment or of Harvard University, or the opinions of any of the scientists mentioned above.

I am grateful to Secretary Bowles and Commissioner Sullivan for ordering a moratorium on logging in DCR watersheds in 2010, and to STAC for its review of DWSP's logging practices and for its policy recommendations going

forward. I also appreciate the opportunity to provide comments on the DWSP's "Response" document, and by extension on the STAC Report, and I look forward to engaging, along with my colleagues, in conversations with Secretary Sullivan of the Executive Office of Energy and Environmental Affairs and DCR Commissioner Lambert, to help inform their decisions about the proposal to re-start commercial logging in Massachusetts' watershed lands.

I need to say at the outset that I have many friends in DCR and admire them and their work greatly, particularly Jim French, whose efforts to protect land from development in the Quabbin Watershed are legendary; Paula Packard, whose tireless work to understand the dynamics of Commonwealth surface waters and wetlands and to preserve them deserves special praise; and Caroline Raisler, who was enormously helpful and diligent with all the details involved in my wife's and my Watershed Protection CR. I also want to recognize the hard and dedicated work of the STAC and of those in DWSP and DCR in general, who put in long hours and give it their all, despite perhaps sometimes having the feeling that they have a thankless job.

But in spite of these friendships and this admiration, I feel very strongly that it is my responsibility to question scientific conclusions when I disagree with them, particularly when it comes to critically important environmental and pubic health questions such as logging in Massachusetts' watersheds. In what follows, I will restrict my comments to logging in the Quabbin Reservoir Watershed, for, as the largest reservoir of surface drinking water in the world, the Quabbin merits the greatest attention and the greatest care.

First, some general comments about the STAC Report and the "Response" document.

- Any scientific report should present a range of opinions and should go out of its way to reveal uncertainties in its conclusions and possible unanticipated impacts, especially when the issues covered are so multi-faceted and complex, and when the systems involved are so poorly understood. Both of these conditions apply to the Quabbin Watershed. There is no serious attention paid in the STAC Report, nor in the "Response" document, to scientific opinions that may call their conclusions and recommendations into question, and no admission of such uncertainties, creating the impression that both of these

documents are defensive and dogmatic in nature, and raising serious questions about their open-mindedness and objectivity. What is just as worrisome is that those who may disagree with the assumptions on which these reports are based are characterized, I am sorry to say, in a dismissive and patronizing way, as if they were misguided and uninformed, not getting the big picture, and motivated by ideological and aesthetic, rather than by valid scientific, concerns. This is hardly the way to win friends and influence people.

- It also seems unwise in the STAC Report and in the "Response" document to hold up DWSP's receiving the first Forest Stewardship Council's (FSC) "Green Certification" for public land management in North America, without also mentioning that the Commonwealth's application for re-certification in 2009 was denied, as its forestry practices were not in compliance with FSC standards. Now, four years later, the Commonwealth is still not FSC "Green Certified." Anyone who knows this history will raise eyebrows when reading these documents.
- Finally, it goes without saying that when you are causing major disturbances to large, critically important ecosystems, the burden of proof is up to you to demonstrate conclusively and convincingly that the potential benefits derived from such disturbances, both short-term and long-term, are greater than the potential risks. Otherwise, such disturbances cannot be justified. In my view, this principle applies very strongly to forest management of the Quabbin Watershed, which, while not an old growth forest and not "pristine," nevertheless has been in large part undisturbed, outside of intensive harvesting, for 80 years or more.

I will argue below that the STAC Report and the "Response" document have not provided conclusive and convincing evidence that the potential benefits from DWSP's forest management plans for the Quabbin Watershed outweigh the potential risks, and, therefore, that there be a continuation of the Moratorium on logging in the Quabbin (as well as in the Ware and Wachusett Watersheds). I have included several primary references from the literature at the end of my comments so that readers can follow my argument and decide for themselves.

Specific Comments

1. Loss of Carbon Storage and Carbon Release

Carbon sequestration is mentioned just one time in the entire 72 pages of the STAC report. Carbon release from harvesting is not mentioned at all. It is hard to understand why this issue does not seem to be worthy of any consideration, given that "forests and their soils contain the majority of the Earth's terrestrial carbon stocks" (a), that deforestation is thought to account for about 20% of total global CO2 emissions (IPCC, 2007), and that forests in the U.S. are said to sequester some 10% of total annual U.S. CO2 emissions (1). There is an extensive literature that uncut forests compared to those that are logged store the greatest amount of carbon, and that the loss of carbon sinks, both in trees and in the soils, is proportional to the extent of harvesting (e.g. see 2, 3, 4, 5). What's more, there is significant soil carbon release from harvesting (5, 6). Forest soils are the largest active terrestrial carbon pool, with over 69% of the total C in forest ecosystems stored in soil (7). While the regeneration of the forest after cutting will eventually result in a sequestering of carbon at an increasingly rapid rate, it may take 20 years or more before it begins to catch up in rate to the amount of carbon sequestered by uncut forests (3), and longer still until the total amount of carbon sequestered is the same.

The plans to cut up to 25% of some areas of the Quabbin Watershed forests over 10 year periods, which will total many thousands of acres over 20 years (judging from past harvesting), will amount to a massive loss of carbon sequestration for the Watershed, and massive soil carbon release. The fossil fuel costs of the chain saws, trucks, and all the other heavy equipment, plus the transport of the logs to their final destinations must be added to these carbon emission calculations as well.

While the release of carbon from soils and the reduction of carbon sinks secondary to DWSP's harvesting operations in the Quabbin Watershed will not push the world towards a climate catastrophe, the fact that the STAC Report does not even discuss this issue, and has not studied carbon storage or release from harvesting activities in the Watershed at all to my knowledge, at a time when we are rapidly increasing atmospheric CO2 concentrations and causing more and more frequent and extreme, wildly fluctuating, and increasingly unstable changes to the global climate, when the major academies of medicine around the world, including our own

American College of Physicians, have called climate change "the biggest global health threat of the 21st Century", when we need to reduce every possible source of CO2 emissions and increase every possible carbon sink, when we need to plant more forests, not cut down those we already have, does not inspire confidence.

And given that in 2008, Governor Patrick signed into law the Global Warming Solutions Act for Massachusetts, which requires the Executive Office of Energy and Environmental Affairs, in consultation with other state agencies and the public, to achieve greenhouse gas emissions reductions for the Commonwealth of between 10 and 25% below 1990 statewide emissions levels by 2020, and 80% below 1990 by 2050, it is hard to understand how DWSPs current proposals for massive cutting in the Quabbin and other Massachusetts watersheds will do anything but make it more difficult for the Commonwealth to achieve these goals.

2. Biodiversity Loss and Ecosystem Impacts

The STAC Report devotes a great deal of attention to its claim that biodiversity will increase as a result of its harvesting policies, and indeed there are studies that support the finding that many species depend on early successional habitat and will do better with the creation of more open spaces and edges in the forest (b). But it all depends on what one takes as a baseline in talking about the populations of different species, and about what species or family of species one looks at. The species that are said to have declined in New England starting from a century ago, such as field sparrows and cottontail rabbits, thrived in the widespread open fields still present then, as the forests had not yet grown back from cutting done throughout the 18th and 19th and even into the early 20th centuries. If the baseline, however, is the original forests in New England, then it is the deep forest species, like Pileated Woodpeckers, Wood and Hermit Thrushes, Barred Owls, and Fishers that one should be measuring now, not the populations of those species present in greater numbers a century ago.

There is also a substantial literature about how widespread timber harvesting in our forests is devastating for many species—such as for salamanders (8, c, d), which play highly important roles in forest food webs (9) and which are among the most abundant group of vertebrates, both in numbers and in biomass, in New England forests (10), and for other

amphibians (e, f). Given the threat of extinction for many amphibian species, it should be important for these species to be considered in any forest management plan. Saying that logging operations will avoid vernal pools is certainly a worthwhile objective, but one that will be very difficult, if not impossible, to accomplish given the extent of logging proposed, but it is the destruction of the forest itself that is the main threat to amphibians.

There are, in addition, threats from timber harvesting, to many other species, including small snakes (g), wood ants (h), some lichen species (i), and understory plants which may not recover for decades (11). [One has to wonder whether Mountain Lions sighted in the Quabbin Watershed in the 1970s and 1980s by extremely reliable sources, with scat confirmation done some 15 years ago, are still around after all the extensive logging and human incursions, such as from the widespread patch clear-cutting done in the Prescott Peninsula.]

But what may be the most significant, and the least well studied and understood, impact of timber harvesting in the Quabbin Watershed is the effect on the forest floor and the structure and functioning of forest soil ecosystems. The loss of nutrients by removing the harvested timber, the changes in temperature and moisture levels in the soils from opening up the canopy, the compacting and destruction of forest floor organisms by the heavy equipment and the creation of roads (j), the inevitable spilling of gasoline and oil from the heavy equipment, these and other stresses resulting from logging operations all will have drastic effects on soil organisms, both in terms of complexity and abundance, including the mycorrhyzae and other soil microbial life, affecting soil fertility, water retention and flow, water filtration, gas exchange (k), nutrient cycling, the flow of aluminum, nitrates, calcium, and other ions into surface waters (l), and other soil processes. These major impacts on soil biodiversity and ecosystem services, some of which may not recover for decades following timber harvesting (12), are barely considered in the STAC Report.

3. Lyme Disease and Invasives

Lyme disease is the most common vector-borne disease in the U.S., with close to 25,000 confirmed cases nationwide in 2011, as reported by the CDC, and close to 10,000 additional cases that are considered probable. There are also a large number of cases that never show up at a doctor's office. From 2004 to 2008, Massachusetts had the third highest incidence of

Lyme Disease of any state in the country, with close to 61 confirmed cases per 100,000 population.

Lyme is a major public health threat for Massachusetts residents, and may be a particular threat for those who live in and around the Quabbin Watershed, particularly for loggers and hikers and hunters who frequent the forest and its edges. While it is very rarely fatal, Lyme can cause, when undetected and untreated (which is common, as the early symptoms of Lyme resemble a bad flu, as the infected ticks may not cause a local skin reaction and are often too small to be seen, as only about ¾ of people get the characteristic "bulls eye" rash, and as early blood titers for Lyme are often negative) significant long term cardiac, joint, and neurologic problems. It is totally anecdotal on my part, but two of my good friends, both Petersham residents, both very healthy, very strong young men who work outdoors, contracted severe acute Lyme disease in the past few years—one had severe meningitis requiring hospitalization, the other encephalitis, from which, after several years, he has not yet fully recovered!

It is well studied and documented that the fragmentation of forests increases the risk of human Lyme disease, a result of creating habitat where the most competent host for Lyme in our region, the White-Footed Mouse, can thrive, and where its competitors and predators cannot (13, 14, 15), thereby increasing White-Footed Mouse populations.

Compounding this problem in the Quabbin Watershed is the fact that it is infested with invasives like Japanese Barberry, which thrive when there is a disturbance of the canopy (16), and there is growing evidence that Japanese Barberry provides a habitat favorable to the Eastern Blacklegged Tick and to the White-Footed Mouse, further increasing the risk of human Lyme disease (17, 18 19).

The STAC Report acknowledges that increased gap formation in the forests by management activities can facilitate the spread of invasive plants, and the "Response" document of Feb. 2013 says that it will address invasive plants through the "Terrestrial Invasive Plant Strategic Management Strategy" without really explaining how it will achieve this goal. Creating gaps in the forest through their logging practices will do just the opposite, increasing the spread of invasives, including Japanese Barberry.

The fact that Lyme disease and its relation to forest fragmentation and to the spread of invasives is not mentioned in the STAC Report or in the "Response" document indicates that the authors are either unaware of this major public health threat or that they do not consider it important enough to address.

4. Money and Jobs

DWSP insists that its commercial logging operations on public watershed lands are not about the money, and quotes 10 year revenue figures for its operations, from 2000-2009 at $6,940,762, so around $700,000 a year. It is not clear whether these are total receipts or net profits. But the MWRA Advisory Board does seem to be concerned about the money, for in its comment on the STAC Final Report, it angrily decries that "nearly $1.5 million in potential forestry revenue" has been lost since the Moratorium was imposed in 2010. If it is not about the money, and the DWSP is interested in causing the least amount of disruption to the forest while achieving its goal of creating a mixed age, mixed structure and species forest, and not reducing nutrients from removing the harvested trees, then why hasn't it proposed leaving the trees on the ground after they are cut? That would then leave the tree nutrients in the forest, and would avoid the massive destruction to the forest floor caused by the skidders and trucks and dozers and forwarders and roads, as individuals with chain saws could do all the work on their own?

There is another issue here, and that it is that the harvesting creates jobs for those who make their living cutting trees and for those who use the timber products. Clearly loggers have one of the most demanding, and most dangerous, jobs of all, akin to commercial fishing, and they have been very hard pressed by this economy, often barely making ends meet. Like commercial fishermen (and fisherwomen), they have to buy or lease their enormously expensive equipment. I suspect that many have been hurt by the Moratorium, and in my view, the Commonwealth, which has implicitly promised them endless work in harvesting trees in Massachusetts watersheds, including the Quabbin, has a responsibility towards them. Perhaps there needs to be a state bond issue for Massachusetts watersheds, to offset the revenue lost by a continued Moratorium, to provide assistance to loggers who are in need (as Federal programs do for fishermen), and to do all the necessary research and monitoring that has not been done but that must be done. Is there a more worthwhile investment in the future of the Commonwealth, in the long-term security of our drinking water and the forest

ecosystem that sustains it? No-one, including loggers and others who have profited from wood harvesting in the watersheds, if they fully understood the risks involved, to themselves and their families, would sacrifice the Quabbin Watershed for a job. Tragically, such trade-offs have been all too common in our country, presented as the only choices available, to the detriment of both the environment and human health.

5. Resilience of the Forest to Large Scale Natural Disturbances

The major rationale in the STAC Report and the "Response" document for resuming large-scale logging in the Quabbin, Wachusett, and Ware Watersheds is that we must plan for the "perfect storm" where there is a massive loss of forest cover in the watersheds by a natural disturbance, at the same time as that there is a massive drought. The contention is that an even-aged forest is highly vulnerable to such a disturbance, whether it be a hurricane or another severe weather event, or an outbreak of pests or disease. And so the argument is that we must create gaps in the forest for regeneration so that there will be a greater diversity of trees, both in type, strucuture, and in age, so that if most of the older trees die at the same time, then there will be diverse stands of younger trees to take their place.

As the Quabbin Watershed is a fairly even aged forest, this argument would appear to have merit, as there is an increased danger of such losses with the spread of pests such as the Asian-Longhorn Beetle, the Emerald Ash Beetle, and Hemlock Woolly Adelgid and diseases like Ash Dieback, all arriving to our region at the same time, and with the prospect of larger, more frequent, more destructive, more long-lasting storms and other extreme weather events secondary to climate change.

But how has DWSP tested this assumption, that creating human disturbances in the forest by cutting thousands of acres of trees is less destructive than the natural disturbances that may occur? The STAC Final Report refers to the ice storm of December, 2008, the tornado of June, 2011, the late-October snow storm of 2011, and Hurricanes Irene and Sandy. There is also reference to the 1998 ice storm. What were the impacts of these events on the Quabbin Watershed? What was the level of damage on intact areas of forest versus those that had been harvested? Were larger, older trees more vulnerable during these events? How did the forest respond in areas where trees were blown down, and over what period of time did it regenerate from these natural disturbances? What

studies were done in harvested areas versus those that were untouched on forest soils and soil ecosystem functions?

From 1980 to 2009, more than 44,000 acres of forest have been cut by DWSP in the Quabbin, Ware, and Wachusett Watersheds, (and in the Sudbury Forest). What experiments have been done to test the hypothesis that regeneration in these areas of thinning, patch clear-cutting, and "shelterwood" cuts has resulted in a diverse forest with multiple species represented? How have invasives, deer and moose browse affected this regeneration?

The STAC Report and the "Response" document both refer to their cutting practices as following "state-of-the science" Best Management Practices that have always been followed, and yet these practices seem to be constantly changing—from thinning during the period of the 1960s to the 1990s to a mixture of "cookie-cutter" patch clear-cuts and "shelterwood" cutting until 2009 to only "shelterwood" cuts being proposed from now on. There is little explanation about why these changes have been made and how each of these practices achieved, or did not achieve, the goals set out by DCR.

We are told that 90% or more of the cut areas of forest, according to the new proposal, will be below 2 acres in size (which will, or course, create even-aged forests up to 2 acres) but there is no figure about the total amount of acreage that will be cut per year or for a 10 year period, only that the total will not exceed 25% of a watershed forest over 10 years. What experiments have been done in the Quabbin Watershed to demonstrate that openings up to 2 acres are necessary? How was the figure of 25% of the watershed forest arrived at? For the Quabbin Watershed, which has some 85,538 acres of forested land, we are talking about cutting down more than 21,000 acres over the next 10 years. Is this what is being planned?

One would think that with such a proposal, there would have been an ongoing large-scale research program in the Quabbin and other watersheds to determine whether the harvesting program DCR is proposing is absolutely necessary. Since this is not mentioned, one can only assume that such studies have not been done.

One such study that has been done, by Dr. David R. Foster, Director of the Harvard Forest in Petersham, Massachusetts and one of the foremost forest biologists in the world, and Dr. David A. Orwig, a Forest Ecologist and Senior Investigator at the Harvard Forest (20), looked at the immediate and long-term consequences of two major disturbances to forests that they created in test plots—one by wind and one by insects—and compared them to the effects of salvage and pre-emptive harvesting, such as has been done in the Quabbin Watershed. The study was done in Petersham, one of the towns in the Quabbin Watershed. What is instructive about this seminal study is that it showed the great resilience of such forest systems to large natural disturbances and concluded that the negative impacts on forest ecosystems are greater with harvesting regimes than they are with leaving the forests alone and allowing them to recover from natural disturbances.

6. Air and Water Quality

Destroying large areas of the forest canopy will serve to lessen air quality, as the canopy is a filter of small and large particulates in the air--from cities, industrial sites, incinerators, cement production, and other sources, binding them so that they do not enter our lungs and cause and exacerbate asthma and other chronic pulmonary diseases. The leaf surfaces of the canopy also serve as chemical reaction sites that detoxify air pollutants like nitric oxides, the precursor of ground level ozone, into harmless compounds (21). Thus the air in and around the Quabbin and other heavily forested areas is healthier for those who live there.

Similarly forest soils act like blotters for pollutants such as inorganic nitrogen (in the form of ammonium or nitrates) and other inorganic and organic compounds. As rain carrying these chemicals falls on the Quabbin Watershed, it percolates through the soil of the forest and is stripped of the chemicals, which are taken up by the plants on the forest floor and by microbes in the soil, and by chemical reaction sites on clay and on the organic matter to which these compounds bind. In a healthy middle-aged forest in New England, like that of the Quabbin Watershed, rain enters with an average nitrogen load of about 8 pounds per acre each year. Stream water leaving these forests often contains less then 1/10th this concentration (22).

By its cutting practices, DWSP is removing large areas of the canopy, and causing severe damage to the forest floor and forest soil ecosystems. Both have the potential of threatening water quality.

In the STAC Report and in the "Response" document, it is proposed that there be water quality monitoring in areas where forest cutting has occurred, with sampling done before the harvesting and continuing through active logging, as well as over a five year period following completion of the logging. The sample sites are to be above and below the sites of forest management.

The DWSP has been logging in the Quabbin Watershed since the 1960s. Can it be that despite having had an active forest management program for more than 50 years, the DWSP, whose principal mandate is to supply clean drinking water to some 2.2 million people, has not been testing whether its timber harvesting has affected our water quality or not?

Conclusion

There are significant potential risks from DWSP's planned logging operations for the Quabbin and other watersheds—increased greenhouse gas emissions, a decline in the populations of many deep forest species, massive damage to the forest floor and to forest soil ecosystems and their functioning, the spread of invasives, a greater risk of human Lyme disease, and a potential loss of the ability of the forest to filter pollutants from air and water. One major potential benefit that has been claimed by the STAC Report and the "Response" document--that cutting forest stands will lead to a more diverse forest, in age, structure, and type, a forest that will be more resilient to increasingly destructive natural disturbances, thereby ensuring the long-term stability and quality of our water supply, has not been tested. DWSP has no data to support this assumption. And one controlled experiment that has looked at this issue, by Foster and Orwig, has concluded just the opposite:

"All evidence suggests that harvesting exerts greater impacts on ecosystem processes than leaving disturbed or stressed forests intact. A conservative alternative hypothesis for the long-term management of watershed lands might be proposed: the elimination of harvesting and its associated impacts (e.g. soil compaction, road development and improvement) will yield forest and landscape conditions that maintain and improve water quality in the face of ongoing disturbances and stresses." (20)

A group commissioned by the Ecological Society of America to study the importance of forest reserves in National Forests, led by Professor John D. Aber, a leading forest ecosystem biologist in the Department of Natural Resources and the Environment, and Provost of the University of New Hampshire, came to the same conclusion:

"We are confident that:

- Despite natural disturbance and successional change, forest reserves are much more likely to sustain the full biological diversity of forests than lands managed primarily for timber production.
- No evidence supports the view that natural forests or reserves are more vulnerable to disturbances such as wildfire, windthrow, and pests than intensively managed forests. Indeed, there is evidence natural systems may be more resistant in many cases." (23)

More than 44,000 acres out of a total of almost 188,000 acres of the Quabbin, Ware, and Wachusett watershed forests (and from Sudbury Forest) have already been harvested from 1980 to 2009, an amount that may be greater than any single natural disturbance, or combination of them. To harvest more (and it would seem, although the reports are vague about the numbers, that an equal amount, as much as 47,000 acres more, is being planned for harvesting over the next ten years), when there is a great deal of evidence that harvesting causes significant harm to forest ecosystems, and when there is no evidence whatsoever that it protects forests in the long run from natural disturbances, (and may, in fact, make them more vulnerable), should be unacceptable for the people of Massachusetts.

The only mandate of DWSP is to provide clean drinking water. There is no evidence that the harvesting plans as recommended by the STAC Report or by the "Response" document will accomplish this, and a vast literature to support just the opposite conclusion, that undisturbed watersheds, compared to those that have been harvested, are best able to provide the highest quality drinking water.

Until DWSP conclusively and convincingly demonstrates, which they have not in my view--through carefully controlled, long-term experiments within their watersheds, done by respected, impartial researchers from many diverse backgrounds, including several specialized in forest ecosystem services, including some who may even question DWSP's logging policies--that

restarting widespread logging in the Quabbin and in its other Massachusetts watersheds is absolutely essential to their short and long term health and to their providing abundant, clean drinking water for the citizens of Massachusetts; until DWSP conclusively and convincingly demonstrates, which they have not in my view, that the benefits of their proposed forest management policies significantly outweigh the risks, the Moratorium on logging in the Quabbin and in other Massachusetts watersheds should be continued.

That, as Gifford Pinchot said in 1905, would indeed be for "the greatest good of the greatest number in the long run."

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From: Eric Hansen
To: Guidelines (EEA)
Subject: Re: Comment on Report of the Climate Forestry Committee: Recommendations for Climate-Oriented Forest Management Guidelines
Date: Thursday, January 11, 2024 2:12:54 PM

I apologize for the multiple submissions, but there were two other comments that I had prepared, but didn't include in my original text below.

The first is that I reject the premise that there is a dichotomy between working lands and natural lands. Just because human manipulation has occurred in an area, doesn't necessarily mean that the area is no longer natural. This creates an immediate separation between humans and the natural world that may or may not actually exist. If we take a long enough look at the history of our forests, they all have had some sort of interaction with humans and to classify managed forests as non-natural is misleading. The majority of the processes that take place throughout the lives of the vegetation and other organisms in most of our forests (including "working lands") are natural occurrences with only occasional human manipulation. I realize that there needs to be a way to distinguish between lands that are actively managed and those that are not, and that this is a common way to do it, but there should be a better and more appropriate set of phrases to use to make the distinction.

Secondly, this report and certain philosophies that helped inform it rely entirely too heavily on forests, particularly our forests, as a solution to climate change. They are an important part of the suite of solutions we'll need but they are not *the* solution. A much more important and impactful solution is to cut emissions. Though that was not the charge of this report and there are other sectors within the governor's office looking at these and other issues, it bears mentioning so that we don't put excessive amounts of importance/hope in carbon sequestration and storage in our forests and don't look closely enough at the root (no pun intended) causes of climate change.

Thank you again—Eric

From: Eric Hansen
Sent: Thursday, January 11, 2024 1:29 PM
To: guidelines@mass.gov <guidelines@mass.gov>
Subject: Comment on Report of the Climate Forestry Committee: Recommendations for Climate-Oriented Forest Management Guidelines

Thank you for providing a platform for commenting on the Climate Forestry Committee's recently produced report. I was not able to submit my entire comment via the online portal, so I am emailing it here.

The draft “Report of the Climate Forestry Committee: Recommendations for Climate-Oriented Forest Management Guidelines” provides a lot of information and promotes important thinking about our forests. Many of the recommendations appear to be balanced and well thought out. One important thread that runs throughout I think misses the mark. Calls for dramatic change in the ways in which forests of the Commonwealth are managed indicates an implicit insinuation that current management goals and practices are either unimportant (or at least less important than they have been historically) or unsuccessful. As a Massachusetts Licensed Forester, I’d argue that they are neither, though there is always need for regular assessment and room for learning and improvement, perhaps now more than ever.

The climatic changes we are experiencing worldwide are not being caused by the ways in which Massachusetts forests are currently managed be it through passive or active management on private or public ownership. The same is true for losses of biodiversity. Forests that are actively managed with long term diversity of species, tree sizes, and age classes in mind tend to provide high quality habitat, enhance resilience, and continue to store carbon, while at the same time sustainably produce forest products that offset or replace the use of more carbon intensive products or fossil fuels. To that end, more focus in the report and in our on-the-ground reality should be given to responsible stewardship of forestlands. Passive management is an important part of that and should be done intentionally in places where it makes sense to do this, but climate-informed active management should be done on most of our lands where feasible and appropriate. Continued and enhanced monitoring is a critical part of any of these processes which the report does a good job of including for many stated issues.

There are a handful of points that I believe are important considerations to be given to final recommendations:

1. Forests are more than carbon and their management needs to reflect that.
2. We need to retain/maintain as many tools and approaches as we can to sustain the benefits that we all rely on (humans and otherwise) including but not limited to wood products.
3. Resilient forests are those that have diverse species, sizes, and age classes and successfully implemented active forest management has those results in a near immediate time frame.
4. Vigorously growing trees are better able to respond to disturbances.
5. There are keystone species of vegetation that passive management does not provide suitable conditions for long-term (i.e., oak), the eventual decrease of which is a major concern for sustainability of our native insect and wildlife populations.
6. Passive management is important and should be done across the landscape but in areas where it makes sense to do it. This includes but does not necessarily need to be limited to

areas that already show old forest characteristics.

7. Active management is also important and needs to be done in areas where it makes sense to do it. This includes but is not limited to sites with limited existing diversity and structural complexity, sites where there are exceptional existing diversity that will not self-perpetual in the absence of disturbance, and where the operation of equipment is suitable.

8. Maintaining our ability to be self-sufficient with what we can and know how to produce in an increasingly unstable world has long-term sustainability and security implications.

9. It is important to have publicly accessible (both physically and cognitively to lay audiences) demonstration areas that act as model forests so anyone can view and understand what is being done where and why. Increasing model (exemplary as the report states) management is important.

10. Decisions of what to do where (or what not to do where) should consider public opinion, but ultimately must be based on long-term goals and scientific data as opposed to current public opinion.

Viewing forests holistically means considering the suite of features and factors that our actions or inactions impact over the short and long terms. In other words, our forests store and sequester carbon, but they are more than carbon, and they are more than a solution to a changing climate. We focus solely on those features of their services to their detriment and the detriment of the myriad creatures and functions that rely on processes that responsible human stewardship can maintain or enhance. Thank you for providing a platform for comment.

Eric Hansen, Managing Partner
Ferrucci & Walicki, LLC
6 Way Rd
Middlefield, CT 06455
Phone: 860.349.7007
Fax: 860.349.7032
Email: eric@fwforesters.com
www.fwforesters.com

From: Steven La Rivee
To: Guidelines (EEA); Steven La Rivee
Subject: Response to CFC Report
Date: Tuesday, January 23, 2024 7:23:55 PM

Greetings

Response to: Climate Forestry Committee Report
From: Steven La Rivee

All Ecosystems need to be Managed

Every ecosystem requires some type of management. Canada took a, hands off approach to their forest management plan. The Canadian Wildfire Season of 2018 lost 18,780,009 acres of land and 45,714,495.57 acres in 2023. What happened to all that sequestered carbon? How much loss of human life, property damage, habitat loss & wildlife loss occurred? This could have been greatly reduced had an active management plan been in place. Every ecosystem will benefit from some level of active management.

Every ecosystem deserves the best management possible. That means that we must never base values on political agendas. The habitat requirements vary for wildlife species. An example is the New England Cottontail Rabbit. This sub-species of cottontail is native to New England. The Easter Cottontail is not, it was introduced in the early twentieth century. They have different habitat requirements. The New England Cottontail is listed as a species of greatest conservation need, threatened, or endangered in every state in its current range. Cottontail habitat requirements contain protective cover of thickets and brush and young trees that are broken up by open areas of grass and other ground vegetation. These areas need to be 25 acres to provide for a viable population of New England Cottontails. We refer to this type of habitat as Early Successional or Shrubland Habitat. How many species of Flora & Fauna are we willing to lose in the name of carbon sequestration? I say one species lost is too high a price to pay.

12 Handpicked members of the Climate Forestry Committee only met 8 times & very little opportunity for public input. The 70 page report that was produced doesn't show much transparency. With such a small group, using terms like many, some & few instead of actual numbers show a lack of transparency.

Page 7 under wood production units of measure used are some and others, once again showing a lack of transparency. How many is quite relevant. It goes on to suggest that others (your unit of measure) to meet our target of net zero, should keep our forest and have other states cut trees to meet the wood needs of Massachusetts. How does that help with the Global Climate Emergency? Trees are still getting cut, releasing their stored carbon and additional carbon from the additional transportation is released. Not to mention the jobs lost in Massachusetts.

I agree that carbon emissions need to be reduced and carbon sequestration can help. However if we fail to realize the consequences of this report we will be ineffective in reducing emissions as other polluters will continue to exploit the earth as trees will be cut to meet

demands and more carbon emission will occur during transportation. All we will accomplish is the loss of the biodiversity of both the flora and fauna here in Massachusetts

The goal of reducing carbon emissions is a valid one. However, that goal needs to be achieved through realistic efforts. Setting a target level and target date and then doing whatever it takes to achieve that target level or time table causes more problems. The CFC wants everybody else to reassess their policies, procedures, and management practices to accommodate their report. Could it possibly be that the CFC report needs to be reassessed to consider the negative effects that it would have on flora, fauna, other ecosystems, jobs, and the economy in Massachusetts.

Respectfully
Steven La Rivee

Submitted via email to: guidelines@mass.gov

TO: The Executive Office of Energy and Environmental Affairs, Office of Climate Innovation and Resilience
FR: Michael Kellett, Executive Director, RESTORE: The North Woods
Zack Porter, Executive Director, Standing Trees
DA: January 24, 2024
RE: Comments on Report of the Climate Forestry Committee: Recommendations for Climate-Oriented Forest Management Guidelines

Thank you for the opportunity to comment on the report of the Climate Forestry Committee. We are submitting these comments on behalf of RESTORE: The North Woods, a Massachusetts-based nonprofit organization and Standing Trees, a New England-wide nonprofit organization.

We consider the report to be a very positive step toward addressing the future of Massachusetts forests. Specifically, we endorse the following actions, which were supported by some, or all of the Committee members. Until these actions are implemented through the revision of Forest Resource Management Plans, and/or codified in administrative rules, we recommend that the moratorium on logging of state lands be kept in place.

Forest Management for Habitat

- The Committee suggested "reducing cutting of maturing forests to create early successional habitats," (p. 29) "increasing the goal for late successional and old-growth habitat" (p. 28), and designating recently cut or otherwise disturbed areas as early successional habitat (p. 29).

- We recommend a halt to all cutting of maturing forests for the creation of early-successional habitats, which are more common than in the pre-settlement Massachusetts forest, and the prioritization of keeping forests intact to allow them to become future old-growth, which is now greatly underrepresented compared with their pre-settlement extent.

Ecological Disturbance

- The Committee "found no ecological rationale for salvage harvesting" and "was deeply skeptical of pre-salvage harvesting (removal before trees are affected by a pest or pathogen) and the notion that it is ecologically beneficial" (p. 30).

- We recommend that salvage logging be prohibited on state lands except to protect public health and safety.

Carbon Stocks and Sequestration

- We note that the Committee "strongly agreed that carbon storage is typically greatest in old forests and disproportionately in the largest trees, and that Massachusetts forests can continue to accumulate additional carbon for many decades if undisturbed, thus underscoring the importance of forest reserves for protection of carbon storage" (p. 31).

- We could not agree more and believe that this is one of the most compelling reasons for greatly expanding reserves.

Resilience

- Some Committee members argued that logging or other intensive management can "increase forest resilience." Other Committee members contend that, "the long history of forest change and recovery from historic changes in climate and natural and human disturbances indicate that little or nothing needs to be done to make forests more resilient" (p. 35).

- We find that there is no credible science supporting the claim that logging or other intensive management increases forest resilience and believe that it this rationale should not be used to justify forest management activities.

Public Water Supply Management

- The report notes that the "Division [of Water Supply Protection] "acknowledged to the Committee that active forest management is not necessary to maintain an abundant and clean water supply" (p. 42).

- There is little or no credible science supporting the logging of Massachusetts state-owned watershed lands for water quality and relevant laws do not require it. It causes significant forest fragmentation and spreads invasive species. Moreover, this practice is highly controversial and the subject of significant public opposition. We recommend that all logging on state watershed lands be strictly prohibited.

Wood Production

- Some Committee members strongly "[viewed] the moral imperative to address the climate emergency as superseding consideration of additional local harvest of timber" (p. 42). The entire Committee supported "first and foremost, societal reduction of resource consumption through efficiency" (p. 43)/

- We strongly agree with these conclusions and oppose proposals to continue logging on state forest lands to maintain or increase wood production. We also strongly

support efforts to reduce wood demand and increase the recycling and reuse of wood, paper, and other forest products. We believe that Massachusetts wood production should come from private lands, which encompass the vast majority of the Commonwealth's forest acreage.

Forest Conservation and Forest Reserves

- The Committee recommended "increas[ing] the Commonwealth's 2050 land conservation goal from 40% to 50% of Massachusetts" (p. 47), "expand[ing] the number and size of reserves" to "10% of Massachusetts forests" (with some members calling for "as much as 30% of forests" (p. 48), and "codify[ing] reserves on state land to provide a higher level of protection than the administrative designation that currently applies" (p. 48).

- We heartily agree with these recommendations. Toward that end, we urge Legislators and the Healey administration to support the bills H.4150, "An act relative to forest protection," and H.904, "An Act relative to increased protection of wildlife management areas," which would expand reserves to about 8% of the Massachusetts land base and codify reserves to ensure that they are permanently protected.

In summary, we believe that the Committee report provides a positive foundation for expanding and strengthening the protection of Massachusetts forests. We urge the Healey administration to embrace legislation to put the provisions discussed above into statute.

Again thank you for the opportunity to comment on this important report.

Sincerely,

Michael Kellett
Executive Director
RESTORE: The North Woods
Concord, Massachusetts

Zack Porter
Executive Director
Standing Trees
Montpelier, Vermont

MASSACHUSETTS SIERRA CLUB

Prompts:

Area(s) of Agreement? Please comment on sections of the report with which you especially agree.

Overall, we are pleased with the careful consideration given to multiple, often opposing perspectives. It appears that the scientific evidence for protecting forests and maximizing their benefits was acknowledged and incorporated into the recommendations. We appreciate the work of the CFC, as well as the moderator who worked to represent both the process and outcomes fairly.

The Sierra Club MA Chapter Forest Protection Team agrees with and supports the following points and recommendations in this report:

- Old and mature forests rarely need to be cut for ecological or climate reasons. The state should increase the number and size of reserves, with particular attention to wildlife areas and corridors, especially on public lands which include larger and more contiguous areas.
- We support codifying reserves on state land to ensure long-term passive management.
- We support that at least 10%, ideally 30%, of the forest in Massachusetts be managed as reserves/GAP 2 designation.
- Increase the 2050 land conservation goal from 40% to 50% of Massachusetts to be consistent with IPCC recommendations (p.47).
- State agencies should be more explicit and transparent about the rationale behind forest management projects and their carbon and climate implications. For example, while limited harvesting for wood products may not harm water supply, we agree with the committee members who argued that managers should not frame logging for wood products in watershed areas as promoting resilience and protecting the water supply, which is not supported by science (p.41).
- Remove the practice of creating additional early successional habitat as a rationale for logging; utilize and manage existing early successional habitat rather than creating new ones.
- Place greater emphasis on increasing late successional and old growth habitat. This is particularly important in Western MA and the watershed areas which extend wildlife corridors from Connecticut and Pennsylvania to Canada.
- Forgo salvage logging for the carbon and ecosystem benefits of dead wood as well as most pre-salvage logging for pests, especially on public land; there is no climate or ecological benefit to salvage logging.
- Reduce (or eliminate) land conversion for infrastructure; we would add that all agencies should look to utilize already disturbed lands to the maximum extent possible before destroying additional natural and working lands (NWLs).
- Further data collection in state forests, with special emphasis on "*[accounting] separately for the effects of different types of land management."* Finding ways to make these data accessible to the public will improve transparency, credibility and public trust of state agencies. This is also consistent with the Global Warming Solutions Act which requires the publishing of any modeling or analysis, any assumptions, and input/output data.
- Update and institutionalize the Best Management Practices manual with the recommendations from this report and incorporate the Healthy Soils Action Plan. Improve monitoring and evaluation of both adherence to the guidelines and short and long-term outcomes in order to study the effectiveness of the revised guidelines.
- Expand the purview of the Forest Reserves Scientific Advisory Committee (FRSAC) to apply to all three divisions.
- Provide funding as needed to state agencies to implement these goals.

Area(s) of Disagreement? Please comment on sections of the report with which you especially disagree.

The Sierra Club MA Chapter Forest Protection team disagrees with the following premises:

- Increasing harvesting on state lands in order to decrease imports; we have not seen analysis of regional supply chains including exports of wood out of MA or economic analysis of the state's wood and paper products consumption that would clarify that this would be better for overall carbon emissions.
- We disagree that “active management for long-lived, carbon-storing wood products [is] an important climate change mitigation strategy.” First, while durable wood products do indeed slow carbon release, the majority of a forest cut for timber does not get converted to wood products. Second, while there is a carbon cost to importing wood, the biological and climate value of forests should be considered. As shown in the CFC report, Massachusetts’ state forests are among the most dense carbon stocks in New England (Figure 2, p. 16). This resource should be preserved intact to the maximum extent possible. Third, this initiative should also look towards reducing demand for wood and wood products altogether.
- We disagree with the portion of the committee arguing that forest management for resilience is necessary for public water supply management.

State Consideration: Please offer your comment for our consideration as we develop the state's response to these guidelines and their implementation by agencies.

Overall, these comments and recommendations do not appear to be clear and enforceable guidelines. We appreciate the continued “pause” in moving forward with state contracts until projects can be reviewed and adjusted to meet final guidelines.

That said, we request more clarity on how the Climate Forestry Committee report will be applied and how and when recommendations will be implemented. What was clear from the report is that there was general agreement on the science regarding the impacts of commercial logging and silvicultural practices. Differences seemed to arise in the application of that science for various and often conflicting goals. Since committee suggestions were not intended to be prescriptive, subsequent policies and practices derived from the report will therefore be more political in nature and subject to specific interests. This is where our concerns mostly lie. Will there be any process for managers to receive feedback or confer with the committee or any other body? What is the timeline for the necessary updates to the Forest Best Management Practices Manual? And how can enforcement be ensured? Until these recommendations have been formalized and properly implemented, we support continuing a moratorium on logging on state lands.

Additional Comment: Please offer any additional comments not covered by the previous questions.

While not specifically recommended, we support preserving public lands to the maximum acreage possible to be designated as permanent reserves. Ideally, we would like to see a minimum of 30% of natural lands for climate and biodiversity benefits, suggested by several members of the CFC (p.48).

Myles Standish and Manuel Correllus state forests are mentioned on page 48 as reserves that require active management to maintain them. If they are reserves, then why is there active management? We encourage ending the extensive management and keeping the reserve designation.

Perhaps the most interesting, as well as divisive, section of the report is that on resilience. It seems that the committee was not able to come to consensus on the precise meaning of resilience, much less how best to manage it. Overall, we support the notion that with the uncertainty of the effects of climate change,

it does not make sense to actively manage forests for what theoretically “might” happen. Clearly better definitions for resilience, as well as metrics that include both short term and long term goals and benefits, need to be researched and developed. We suggest that this be accomplished by an outside advisory group, such as the CFC, rather than by state agencies.

Will there be formal follow-up with the three state agencies (DFW, DCR, & DWSP) and EEA to determine what CFC report recommendations were implemented and are they having the intended results? If so, describe the follow-up process (e.g., through annual plan report-outs, audits, etc.); how this is reported to the Governor, legislature, and public; and how often this feedback will be provided.

1. First and Last Name

Mark Ashton, Mark Bradford, Bradford Gentry, Thomas Graedel, Timothy Gregoire, Sara Kuebbing, Xuhui Lee, Robert Mendelsohn, Joseph Orefice, Alan Organschi, Pete Raymond, Barbara Reck, Jim Saiers, Karen Seto, Gerald Torres, Yuan Yao.

2. Email Address

Joseph.orefice@yale.edu

3. **Affiliation (Drop down menu)**

4. **Job Title and Organization**

Ashton: Senior Associate Dean of The Forest School at the Yale School of the Environment (YSE) and Morris K. Jesup Professor of Silviculture and Forest Ecology
Bradford: Professor of Soils and Ecosystem Ecology, YSE
Gentry: Senior Associate Dean of Professional Practice; Frederick K. Weyerhaeuser Professor in the Practice of Forest Resources Management and Policy; Co-Director, Yale Center for Business and the Environment, YSE
Graedel: Professor of Industrial Ecology (retired), YSE
Gregoire: J.P. Weyerhaeuser Professor of Forest Management, YSE
Kuebbing: Director of Research, Yale Applied Science Synthesis Program, YSE and Yale Center for Natural Carbon Capture
Lee: Sara Shallenberger Brown Professor of Meteorology, YSE
Mendelsohn: Edwin Weyerhaeuser Davis Professor of Forest Policy; Professor of Economics, YSE
Orefice: Lecturer; Director of Forest & Agricultural Operations, Yale Forests, YSE
Organschi: Senior Critic; Director of the Building Lab, Yale School of Architecture
Raymond: Senior Associate Dean of Research & Director of Doctoral Studies; Professor of Ecosystem Ecology, YSE
Reck: Senior Research Scientist, Center for Industrial Ecology, YSE and Director Material Systems, Bauhaus Earth.
Saiers: Clifton R. Musser Professor of Hydrology, YSE
Seto: Frederick C. Hixon Professor of Geography and Urbanization Science, Director of the Hixon Center for Urban Sustainability, YSE
Torres: Professor of Environmental Justice and Professor of Law, Yale Law School and Professor of Environmental Justice, YSE
Yao: Assistant Professor of Industrial Ecology and Sustainable Systems, YSE

5. **Area(s) of Agreement? Please comment on sections of the report with which you especially agree.**

In general, we find that we are in strong agreement with the Committee in the following recommendations:

1) General Recommendation #1 (page 26): Agencies should strategically apply management approaches and prioritize forest management using a “landscape scale approach”. We agree that there should be no blanket management policy (for example, ‘touch nothing’, ‘cut everything’) prescribed for state forest lands. No one forest is the same, thus management options should never be uniform across all forests. We agree that some state lands should be

placed in reserve for their ecological or cultural value, while other state lands may be well-suited to remain working forests. But this has already been done. The Massachusetts 2020 Forest Action Plan estimates that approximately 40,000 acres (7.6%) of state-managed forest are currently set-aside from timber harvest. If the state reconsiders the wildlife habitat goals determining the proportion of state lands in various habitats (early successional, young forest, etc.), this assessment should be open and transparent, based on the best available ecological and wildlife science, and explicitly consider trade-offs among meeting biodiversity goals, carbon goals, or socioeconomic goals that could occur with habitat goal adjustments.

2) General Recommendation #4 (page 26): We agree that forest management should use silvicultural prescriptions that emulate natural disturbance regimes historically associated with the local site and forest community (1-8). We note here (and describe in more detail below), that this type of management is NOT LIKELY TO OCCUR on privately-owned forest land in the state without policy interventions (9).
3) General Recommendations #5 & #6 (pages 26-27): Commonwealth land managers and agency leadership must be empowered to make considered decisions, informed by public input, that involve tradeoffs and seek to achieve multiple goals. Forest should never be managed solely for carbon, but for multiple benefits including biodiversity protection, timber and non-timber resources, and cultural values. There will sometimes be synergies in management decisions that meet multiple goals; there also will be conflicts and tradeoffs at other times. Decisions should also be revisited periodically, and state agencies should have the flexibility to change management approaches as society's values or the science of forest management change. This point emphasizes the importance of Recommendation #1, above, that management decisions should be made for both the forest under management consideration and that forest's placement in the larger forest landscape. Landscape planning and prioritizing certain goals in certain areas is the only way to meet the multiple different objectives Massachusetts has for its forest.
4) Keep Forests as Forests: The report notes that most forest acreage AND carbon loss in Massachusetts is from conversion of forestlands to non-forested lands. Forest harvest has a 75% smaller footprint than forest conversion, and unlike forest conversion for human settlement or agriculture, harvested forests remain forests (just ones with initially fewer and younger trees) that re-sequester carbon over time.

Area(s) of Disagreement? Please comment on sections of the report with which you especially disagree.

We understand there was disagreement among authors of the report. We agree with and emphasize the following important points raised by some committee members:

1. **Avoid binary classification of management.** The report regularly pits active forest management against no management, as if the options for such a choice are binary. Figure 6 attempts to address the spectrum of management, and we applaud the efforts of the authors to describe the continuum of management actions between "active" and "passive". However, we feel that even trying to create a continuous scale for management actions suggests an inherent ranking among approaches. Figure 6 suggests that certain silvicultural systems, such as group selection or shelterwood, are more "active" than other silviculture systems like annual firewood harvesting. Should an even-aged regeneration system which includes timber harvesting once every 100 years be considered more "active" than annual firewood harvesting or selections systems which dictate logging on 10-20 year cutting cycles? We question whether these

distinctions are accurately describing "activity"? We caution any policy attempts to distill forest management decisions to a single axis for simplicity, and emphasize again (as with general recommendation #1, in areas of agreement), that management decisions must instead be place-based, site-specific, and capture the desires and needs of the communities living within and around the forests, as well as broader environmental and socioeconomic contexts. We suggest that forest management approaches instead be framed as options to meet certain objectives, such as resource needs and forest resilience goals.

2. **"Active Management" is a dynamic and flexible way to protect and care for forests in a changing climate.** "Active" management can happen in many forms and timeframes (10). Restricting any tree cutting from sites removes future tools that may be needed to ensure forests meet the needs of society – including growing long-lived big trees. "Passive" forest management (doing nothing) allows forests to develop on trajectories that may or may not result in long-term carbon storage. There is research which suggests that actively managed forests in New England, using specific silvicultural techniques to manage for multiple age classes, can result in healthier long-lived trees and greater long-term carbon sequestration and benefit other forest ecosystem services by generating more resilient forests (11).
3. **Multiple-objective forest management is needed.** We caution the state not to ignore other forest management objectives for the sake of carbon storage. Forests provide critical resources for the people of Massachusetts and periodic forest management is compatible or necessary to meet other objectives like promoting recreation, biodiversity, air and water pollution reduction, climate resilience, and generating forest products.
4. **Forest management can increase forest resilience to climate change and other forest stressors like pests and pathogens.** There should be no question that forest management, with the proper objectives and implementation, can increase resilience. Ecosystem resilience increases with different age classes, species diversity, and structural aspects of forests. Active forest management is the only tool we have to create this type of resilience. Relying on natural disturbance to create resilience is not certain. Like all natural systems, natural disturbances will result in uneven changes in forest ecosystems through time at whatever pace, location, and scale that "nature" decides. Change in Massachusetts' forests is occurring regardless of active management or not. Invasive pests, anthropogenic-induced climate change, and forest fragmentation due to development are new and increasing stressors on our forests. And the fact that these forests are already legacies of the most significant human impact on them to date– colonial land clearance – makes them homogenous in age and structure and predisposed to invasive insects, disease, and climate disturbance. Active management enables forest stewards to balance these adverse effects on forest ecosystems by periodically nudging the forest in a more resilient direction. Active forest management is the method we have to ensure that our forests under pressure will be resilient to ongoing and future disturbances. Active forest management can promote the forests we want and need for the future for biodiversity, timber production, carbon storage, water provision, and many more desirable services of forest lands.
5. **Mature forest can be managed forests**. We agree that mature forests are important, but mature forests can result from "active" forest management. In other words, "passive management" is not the only route to fostering "mature forests". The 'mature' forests of pre-colonial America were regularly "actively" managed by indigenous peoples before colonists forcibly removed indigenous communities from the forests they stewarded. Another example are the oak forests of the Spessart region of Germany, where oaks are grown on 200-300 year rotations with an intentional structured canopy and understory. Closer to home, a recent publication from researchers at the University of Vermont demonstrated using field measurements and modeling exercises that some forms of "active" management can increase

structural complexity and carbon stocks relative to other forms of "active" management or passive no harvest (12). These are just a few examples of how tailored "active" silvicultural prescriptions that are forest- and site-specific can enhance desirable features within mature forests. Importantly, these forests management actions make forests better able to withstand and recover from disturbances in ways that passive management will often fail to achieve. *The climate crisis needs forest managers to be innovative, not inactive.*

6. **Early successional habitat should be of concern.** The report recommends reducing the amount of early successional habitat while increasing the amount of mature forests. Early successional habitat, and associated rare species, will be significantly reduced when active forest management for such habitat is limited. While natural disturbances, like hurricanes, will create early successional habitat over time, these disturbances are rare enough that early successional species may disappear before another major disturbance event creates more early-successional habitat. This is especially concerning because connectivity of habitats in southern New England are limited by human development. The Commonwealth should pay particular attention to the fact that deliberate, early successional habitats are often the fastest forest lands to recover after major disturbances like hurricanes. If they are not present on the landscape, recovery of the Commonwealth's forests will be slowed.
7. **Local Wood Production can promote more sustainable forest management in Massachusetts and deter detrimental forests practices outside the Commonwealth:** Massachusetts can control and enhance the type of wood it uses and produces when that wood is grown in its own forests. Relying on Massachusetts wood demand to be sourced from other regions results in the state having no control over the type and quality of forest management its wood is sourced from. This type of "not-in-my-backyard" wood sourcing approach could lead to the Commonwealth's exploitation of resources from more ecologically sensitive places, such as primary tropical forests, in the world. There is historical precedence for this type of exploitation. When Boston depleted its firewood resources in the 18th century, the city's demand for wood led to deforestation of coastal islands in other parts of New England. If Massachusetts wants to use wood products and address climate change, then sourcing wood locally empowers the Commonwealth to meet both objectives with the most accurate carbon accounting possible. We note that other Commonwealth climate planning documents recognize the importance of considering wood product sourcing regions. Strategy L4 of the "Massachusetts Clean Energy and Climate Plan for 2025 and 2030" is to "incentivize long-lived, durable wood products" and the report text highlights that sourcing from Massachusetts is better than sourcing from other regions with higher ecological impacts or less regulations on harvesting. In short, Massachusetts has the capacity to shape its environmental impact when it manages its own forests, acknowledging its role as a global participant in the stewardship of forest lands.
8. **Wood products can produce climate benefits**. Carbon stored in wood products is an important part of the climate conversation around managed forests. States like Massachusetts should be incentivizing management which supports the production of long-lived forest products and renewable energy such as firewood. There is also evidence that the use of wood products as substitutes for steel and cement in construction is a much more efficient solution to climate mitigation than business as usual.

1) **The "best" approach to managing forest for carbon and climate mitigation will be site-specific.** There is no scientific consensus that a single type of forest management action is the "best" for carbon storage and climate mitigation. This is, in part, because we are creating models and projections of an unknown future. There is growing evidence, however, that forest management can lead to carbon benefits, but these benefits may accrue over different time-scales or within different carbon pools (10-13). And, all forest carbon projection models—for both passive and

actively managed forests—are built off a series of assumptions of future climate, disturbance, social, and economic conditions. An adaptable and flexible forest management policy for the Commonwealth would likely involve setting benchmarks and guardrails for forest managers to follow when determining forest management plans. The Commonwealth has a robust long-term dataset of forests conditions on their state lands and a deep bench of experts in forestry, forest ecology, forest management, and forest modeling with the state Department of Conservation & Recreation. We think that the best management decisions will only be made considering the current forest conditions, the desired forest outcomes, and using transparent data-driven models and forecasts for state-owned forest lands.

9. **We still have more to learn about soil carbon stocks.** We cannot quantify the relative effect of forest management practices on soil carbon stocks. We strongly agree with the Committee that soils are an important (and often overlooked) carbon pool in forest ecosystems, and that the Commonwealth should enforce (on public and private lands) best management practices in forests that reduce soil disturbances and promote organic buildup (downed woody debris, leaf litter, etc.) in soils. However, these recommendations are not based on extensive high-quality, empirical data that demonstrates the magnitude of effect of forest management practices on soil carbon stocks. That data does not exist. However, some data does exist and suggests that timber harvesting on New England soils has minimal impact below 10-cm soil depth and the top soil layers recover nutrients and carbon relatively quickly post harvest (14-15). However, more prescriptive management recommendations for protecting or building soil carbon stocks cannot be evaluated at this time without additional scientific studies.

6. State Consideration: Please offer your comment for our consideration as we develop the state's response to these guidelines and their implementation by agencies.

We applaud the authors of the report for their transparency regarding where the expert committee members were in strong agreement or disagreement over recommendations. In general, we hope that the Commonwealth will interpret the Committee's level of agreement on topics as an assessment of "confidence" in a particular finding. For topics that Committee members found unanimous agreement, the state may interpret that a diverse group of scientists have "high confidence" that a policy or practice will be a net benefit. For topics that Committee members found strong disagreement, the state should interpret that to reflect "low confidence" among scientists that a policy will be a net benefit. We encourage the state to prioritize Committee recommendations with high agreement and to spend more time evaluating the impacts of recommendations that stirred strong disagreement. Some of this disagreement appeared to stem from ideological differences in wildland protection, or differences in a 'preservationist' oriented philosophy that seeks to limit human extraction from nature versus a 'conservationist' oriented philosophy that seeks to sustainably utilize natural resources. This is an old debate, but more recent sustainable development pathways repeatedly advocate for the latter. A conservationist approach to land protection and management may be especially relevant for the state's forest lands given the thousands of years of human management that shaped the current forests of today, and an opportunity to reset forest trajectories that are still recovering from the massive impacts of deforestation by European colonists.

We also note that the state should consider external factors outside the scope of the Committee's purview for this report. This is especially true for areas where there was strong disagreement among Committee members. The Committee considered a wide range of topics regarding the management of state-owned forest resources. However, as the Commonwealth applies the Committee's findings to

state-wide policy, we note that the impact of any decisions on how the state manages its forests will also affect the 83% of Massachusetts forest lands that are not owned or managed by the state.

An important consideration of any future policy should evaluate the "activity shifting leakage" impact of state harvest bans. The state may opt to stop harvesting wood on state-owned forest land. That does not necessarily stop harvesting activity in Massachusetts' forests. It is well-demonstrated (especially in national and international carbon markets) that preventing one forest from harvest likely shifts harvesting activities to another forest (16-17). We encourage Massachusetts to estimate how much activity shifting leakage has occurred over the past few years when harvesting activities were halted on state-owned lands. Did production for mills in the region decline, or did wood products continue to flow into mills? Where does Massachusetts acquire its wood products? What is the carbon impact if a much higher proportion wood was imported rather than produced within the state?

The Commonwealth's total carbon footprint may remain the same with strict bans on forest harvesting if privately-owned forests in the state or forests in the region (or even globally) are harvested instead. If consumption of wood remains the same in the Commonwealth, there is potential that the carbon footprint of the state may increase given additional transportation costs, as well as lost economic opportunity for the state. If forest harvesting on private land increases, we are concerned that those operations will have less oversight regarding 'sustainability' and adherence to many of the best management practices highlighted by the Committee. Particularly concerning is that prior research has shown that exploitative forest harvest practices are quite common in the region on private forest lands (9). If reduction in state-forest harvests leads to increases in private-forest harvests, it is likely that the private harvests are doing more harm to the Commonwealth's forest relative to state-sponsored harvests overseen by state forest professionals with expertise and knowledge in implementation of best forest management practices. This harm may be accentuated if the Commonwealth chooses to limit its forest management expertise by banning management on state forest lands, whereas a positive and collaborative relationship between state and private forest management seems likely if the Commonwealth focuses on supporting effective management.

7. **Additional Comments**

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From: Laurel
To: Guidelines (EEA)
Subject: Trees are our life line - Comment on the state"s CFC Report
Date: Monday, January 22, 2024 10:41:02 PM

Comment on the state's CFC Report from Laurel Facey

I am a member of the Trees as a Public Good Network and a Massachusetts voter and taxpayer and I am writing to comment on the CFC Report. My main point is that climate considerations should be the main criterion for all forest and tree management decisions on public lands as the science committee was charged with exploring.

I agree with the following points of the CFC Report. (1) We should follow the climate-based science that all MA public forests should be minimally disturbed, passively managed, and PERMANENTLY PROTECTED FROM LOGGING so they are allowed to grow and age to maximize carbon sequestration, ecological integrity, soil health, and climate mitigation. (2) The state should buy more land for permanently protected (no-logging) reserves with a goal of reaching 30% of all MA forests in permanent reserves by 2030 and 50% by 2050. (3) The state should provide incentives for private landowners to permanently preserve forests and urban trees. (4) We should follow the climate-based science that we should NOT log in watersheds/reservoirs as it can endanger the public water supply. (5) The state should establish small forested lands in exurban and urban settings as permanently protected reserves.

I disagree with the following points of the CFC Report: (1) MA public forests should NOT serve any economic goals, for example for the wood industry or the land-trust companies. The majority of MA forests are privately owned; these privately owned forests can serve economic goals. (2) The state should NOT log in public forests, especially not in reservoir areas and watersheds. (3) The state should NOT log for early successional habitat and its associated species. There are many such places, and when we search for explanations for the loss of wildlife, we should first look at our use of pesticides. We need to allow our mature forests to reach old-growth stages, where the climate benefits are much greater. (4) Incentives for private landowners to permanently preserve forests and trees should NOT replace permanent protection of all public forests.

I urge the state to prioritize the following considerations in implementing the CFC

Report: (1) Permanently stop logging on public lands; all projects should be immediately reevaluated for climate (not economic) considerations. (2) Planting trees in urban areas is not sufficient; we need to *preserve* existing urban tree canopy, including making small permanently protected reserves, such as the NEMT Forest (13 acres) and the 4 acres of woods on Morton St. in Dorchester, Boston.
Laurel Facey,
Wendell, MA

The Trustees of Reservations
200 High Street | Boston, MA 02110

January 24, 2024

Secretary Rebecca Tepper
Executive Office of Energy and Environmental Affairs
100 Cambridge Street, 10th Floor
Boston, MA 02114
guidelines@mass.gov

RE: *Trustees comments on Climate-Oriented Forest Management Guidelines*

Dear Secretary Tepper:

The Trustees of Reservations is grateful to the Healey-Driscoll Administration's leadership in maximizing the use of Natural and Working Lands to meet the state's ambitious climate goals and for convening the Climate Forestry Committee. We also appreciate the committee's hard work and dedication to conserving, managing, and restoring Massachusetts' forests, and this opportunity to share our comments on the committee's recently released "Report of the Climate Forestry Committee: Recommendations for Climate-Oriented Forest Management Guidelines."

The Trustees preserves, for public use and enjoyment, properties of exceptional scenic, historic, and ecological value in Massachusetts. Today, 133 years after our founding, we are Massachusetts' largest conservation and preservation organization. With the support of our 100,000 member households, we care for 123 properties and 27,000 irreplaceable acres. As stewards of over 20,000 acres of forest land, we applaud the Healey-Driscoll Administration's *Forests as Climate Solutions Initiative* which recognizes the vital importance forests of the Commonwealth have in addressing the dual crises of climate change and biodiversity loss.

We support many aspects of the Climate-Oriented Forest Management Guidelines (guidelines) and agree that **land conservation** is of paramount importance to keeping forests as forests and providing for additional carbon storage, protecting water, habitat, and biodiversity, and providing outdoor recreational opportunities and scenic values. We applaud the description of how the recommendations will be applied – that they be flexible, adapted to each location, and consider a range of management activities from passive to active. Below, please find a list of general concepts that we support in the guidelines. In some cases, we offer additional perspectives and recommendations for consideration.

1. **Forests are more than carbon.** The Trustees are pleased to see this recognition in the guidelines. Massachusetts forests should not be solely managed for carbon, but rather for a range of benefits including climate resilience, habitat and biodiversity conservation, water supply protection, as well as recreational and scenic values. As noted in the recommendations, management of specific forested areas will require tradeoffs, and these should be thoughtfully considered by managers with input from community leaders and affected stakeholders, and decisions made with the best information available. We hope the state will also prioritize the conservation of forests that provide critical ecosystem services, such as pine barrens, riparian forests, and interior forests, which are threatened by changing land uses.

2. Nearly all the forests in Massachusetts continue to recover from past disturbances and face novel **forest threats**. These include non-native pests and pathogens, non-native invasive plants, poorly planned development, and climate change (changes to storm frequency and intensity, droughts, floods, and temperatures). These threats should be considered in all management scenarios whether passive or active. Some of these threats extend beyond individual stands and should be managed at the landscape scale. One such threat is **deer overabundance**. The Nature Conservancy and Northern Institute of Applied Climate Science identify "protecting seedlings from deer browse" in their top 10 climate-smart forest management practices as herbivory limits the ability of forests to respond to climate changes.[1] The guidelines minimally reference this threat yet more emphasis is greatly needed to develop a statewide approach to managing overabundant deer populations across boundaries. We encourage the state to allow managed hunts on more state lands and support deer management on adjacent nonprofit and private lands. We would be pleased to help develop a program with the state, as we have built a well-respected and effective deer management program on our own properties.

3. We support the state's efforts to be **transparent and intentional** with forest management plans and for explicitly including why decisions and/or tradeoffs are made. We agree that management plans need to address site specific conditions while maintaining flexibility to address the goals and threats for each stand. Specifically, it can be critical to maintain early successional habitat and, in some cases, create it, to support biodiversity in Massachusetts as well as increase forest resilience. The guidelines need to be flexible so as not to hamper the best path forward under specific site conditions.

4. The Trustees applauds efforts toward **holistic statewide habitat management** to support biodiversity and carbon storage across different agencies and landowners, based on the most suitable locations for the habitat rather than property ownership. An example is management of globally rare barrens ecosystems where prescribed fire is necessary to support rare native species and their habitat. In addition, management of early successional habitat is important to managing the full suite of biodiversity in the state. The guidelines should allow state agencies to plan and implement early successional habitat management based on transparent planning that considers tradeoffs between carbon storage and biodiversity based on clearly defined goals. Habitat management goals should consider the history of the landscape, but also the current importance of native species whose historic range may have constricted due to human influences elsewhere.

[1] *Health Forests for Our Future: A management guide to increase carbon storage in Northeastern forests*. 2021. The Nature Conservancy and Norther Institute of Applied Climate Science.

5. Implementing the guideline's recommendations will require **additional capacity** for state agencies, particularly on-the-ground staff with the knowledge to assess tradeoffs, make informed decisions that address threats, collect data, and ensure long-term goals are met. Foresters and timber harvesters will need to be trained. The state could find qualified staff via the forestry program at the University of Massachusetts, Amherst. We also hope the state will encourage and incentivize more public-private partnerships such as the recent project completed by Essex County Greenbelt and the Department of Conservation and Recreation to protect 2,000 acres at Lynn Woods, a publicly owned parcel.

6. Forest Reserves were designated by the Department of Conservation and Recreation through the Forest Futures Visioning Process over a decade ago to "conserve large contiguous blocks of high-value ecosystems" and allow for natural processes to take place. It is our understanding that this designation, however, is not employed by the other state agencies and programs. The Commonwealth could benefit by expanding **Forest Reserve designations** to lands held by multiple agencies and programs, as well as targeting new acquisitions for forest reserves. We encourage more collaboration between divisions, as well as with private landowners, nonprofit and municipal lands, especially around unique natural communities, areas significant for biodiversity, and large forest blocks. Forest reserve designations can be a tool to support the management of late successional forests which will take hundreds of years to fully develop. The future is uncertain, however, and additional science around the dual crises of biodiversity and climate change may require management that is unanticipated at this time. The state should strive to balance passive reserve management with more active management for resiliency according to best practices across its forest holdings regardless of agency ownership.

7. The Trustees encourage the Commonwealth to provide new **incentives to create private, municipal, and nonprofit forest reserves** and would be happy to partner with agency officials to explore the creation of new grants and incentives that codify these protections and determine for what duration the designation would last. These reserves will be pilot sites where we learn more about the natural resiliency of our ecosystems to a variety of stressors over 100+ years while also providing for biodiversity and habitat, carbon storage, water protection and scenic values. We welcome the opportunity to use some of the Trustees forests as laboratories for this work.

The Trustees continue to collaborate with agency officials and lawmakers to develop and implement new policies, incentives, and funding sources to support many of the recommendations outlined in the guidelines. The Trustees is appointed to the *Global Warming Solutions Act Implementation Advisory Committee's Land Use and Nature-Based Solutions Work Group* and dedicate staff to administrative and legislative advocacy to support forest conservation and management. For example, to increase the pace of forest conservation, we lead efforts to advocate for increased capital investments in land acquisition, including new and expanded grants for nonprofit land trusts and conservation organizations. We also hope the administration will expand the Conservation Land Tax Credit, a highly credible, effective, and successful land conservation program that suffers from a chronic two+ year backlog. We also support an expansion of the M.G.L. Chapter 61 forest management program for carbon benefits to incentivize the

use of climate smart forestry practices to manage these lands for carbon storage.[2] [3] And legislation is pending that will limit state incentives that enable industrial-scale solar arrays in our forests, especially in globally rare pine barrens.

The Trustees brings decades of experience and sophisticated decision-making informed by latest and best science to enhance carbon sequestration in Massachusetts forests. Please let me know when you are available to meet to discuss these issues and other innovative ways in which The Trustees can support the Healey-Driscoll Administration's forest-based initiatives. We look forward to partnering with you and supporting the use of Natural and Working Lands to reach the state's ambitious climate targets.

Please reach out to me anytime at cdittbrenner@thetrustees.org.

Thank you for your leadership and consideration.

Sincerely,

Cynthia Dittbrenner
Interim Vice President Conservation & Resiliency

[2] See Wisconsin's forest management program requiring 25- or 50-year enrollments. See Managed Forest Law (Sections 77.80 to 77.91, Wis. Stats.) and administrative rules (Chapter NR 46, Wis. Adm. Code)
[3] https://dnr.wisconsin.gov/topic/forestlandowners/mfl