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Integrating policy and ecology systems to achieve path dependent climate solutions

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ABSTRACT

The Paris Agreement emphasizes regional "bottom-up" policy solutions to address climate change. We argue that efforts to develop these regional solutions require treating ecological and policy processes as interacting together. Through this approach, policy decisions affect ecological processes, and subsequent ecological changes create feedbacks into policy and political processes. Such a re-orientation can help uncover heretofore hidden "policy triggers", thereby offering new and perhaps more durable climate solutions. We illustrate this with a case example of the interplay among boreal forest natural resource management policies that created path dependent extractive industries, which in turn, triggered path dependent carbon cycling processes within boreal ecosystems, causing higher carbon emissions. The ability to apply path dependency analysis in general, and identify creative solutions in particular, requires a much more systematic conversation between ecological and policy sciences. We illustrate how path dependent innovations can be identified and triggered, through our own integration of ecological and path dependency analysis: the use of arguably "easy to change, but hard to reverse" policy decisions over hunting licenses. This trigger is not just identified because it is consistent with climate science for managing predator-prey relationships towards lower carbon emissions, but because it holds promise in creating a durable solution even in the face of pressures to reverse course. Hence, the policy is also expected to help lower carbon emissions, in the same way forestry policies (inadvertently) helped increase carbon emissions over a century ago.

Our goal is not to argue that this is the only or best solution that might emerge from integrating policy and ecological sciences, but rather to highlight how unforeseen, practical solutions can be nurtured when fostering conversations among largely qualitative historically inclined policy scientists that focus on the complex casual impacts of non-generalizable "critical junctures", and largely quantitative ecologists seeking general patterns with complex ecosystems. We advance the significant work underway by path dependency focused policy scientists by calling for greater integration of knowledge across these disciplines that currently tend to treat knowledge from the other as "exogenous" shocks.

1. Introduction

The Paris Agreement on climate change has been heralded as a major step toward designing and implementing solutions capable of stemming atmospheric carbon build-up, thereby preventing a rise in global mean temperature beyond 2 °C (Hallegatte and Mach, 2016; Rogelj et al., 2016). One of the key features of Paris Agreement is that it eschews a single "top down" binding agreement in favor of nationally determined commitments from Party countries. Proponents of this flexible approach claim it allows for innovation by enabling national and local governments to develop their own unique "bottom-up" (Sabatier, 1986) approaches that might better align the spatial scale of a solution with the spatial scale of societal interests and values (Rogelj et al., 2016; Savaresi, 2016; Young, 2016). Conversely, critics claim it "doubles down" on a "commitment" approach that has, for the last 30 years, failed to sufficiently reduce emissions (Clémençon, 2016). Both supporters and detractors agree that whether, when, and how, the Paris Agreement might succeed depends on how national and local governments, as well as the private sector, might uncover "bottom up" solutions (Bernstein and Hoffmann, 2018) capable of creating lasting effects with expanding impacts over time.

We advance an approach to help policymakers think about how to

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develop low-carbon policies consistent with national-level commitments for the Paris Agreement. We illustrate our approach by building a case example around recapturing and storing atmospheric carbon in forest ecosystems. Ecologically, carbon capture and storage in forests seems simple, sufficiently straightforward, and broadly actionable among different regions. However, we demonstrate that multiple, often conflicting societal values to protect, conserve or exploit different parts of any forest ecosystem means that a regional solution could fail to contribute toward meeting these global targets to reduce atmospheric carbon buildup. We argue that developing regional climate policy for forest carbon recapture requires much more explicit a priori reasoning about how to entwine policy solutions with a regional forest ecosystem's dynamics than has been done to date in the vast majority of climate scholarship, let alone in practice. The reasoning processes we describe conceive interrelated causal pathways of policy and ecological effects. Our intent is not to prescribe any specific policy solution. Rather we illustrate how failing to engage in such an a priori process could lead to suboptimal policy solutions for achieving policy goals, or worse yet, fail to consider policy options that may be more effective and durable (Howlett and Mukherjee, 2018). Hence our proposed approach does more than reaffirm a conventional science-policy interface in which scientific information merely feeds into and undergirds policy decisions. Instead, by treating policy and ecology as enmeshed systems, it becomes possible to explore "progressive incremental steps" (Cashore and Howlett, 2007; see Table 1) that can create mutually reinforcing ecological and political path-dependent outcomes to reconcile conflicts and enhance the durability of policy solutions (Pierson, 1993). In such a way, science and policy processes inform each other by recognizing path dependencies created by potential policy solutions (Levin et al., 2012; see Table 2).

2. Adopting a path dependent approach

The concept of path dependency has been applied by sociologists (Mahoney, 2000), political scientists (Pierson, 2000), and institutional economists (North, 1990) as a way of recognizing, and understanding, the "progressive incremental" (Cashore and Howlett, 2007) processes through which unintended or unforeseen consequences can create entrenched processes that would be difficult to alter once underway (Page 2006). Levin et al. (2012) argued that path dependency analysis, drawing on "forward reasoning" techniques (Bernstein et al., 2000) could be used not only to develop better explanatory projections, but also to prescribe courses of action to help the study, and practice, of policy instrument design (Howlett, 2019) in ways useful for ameliorating climate change. They identified what they called "super wicked" problems, denoted by four key features: time is running out, no central authority, those causing the problem also want to solve it, and the future is being discounted irrationally. They drew on Page and Scott (2006) to explain the path dependent logics of previous policy instruments, as well as how such processes could help scholars, stakeholders and government officials "brainstorm" innovative ideas for creating such processes in the future. Page's review was important because he identified four often simultaneous processes that careful policy design efforts might be able to unleash: immediate *lock-in* in which reversal is immediately difficult (such as privatizing public land, since expropriation would require compensation); *increasing returns* such that the economic benefits of the intervention accelerate over time (such as smart phones providing increasing services); *self-reinforcing* in which the costs of reversal increase over time (such as, say, reversing the national highway transportation system today versus 70 years ago when it was still being built); and *positive feedbacks* where the population the intervention covers expands to include others in ways that reinforces, rather than undermines, the original target population (such as expanding universal health care coverage from a local to national jurisdictions). Levin et al. (2012) reviewed how these processes can help explain the durability and effectiveness of carbon-friendly policies, such as the German government solar panel "feed-in tariff" programs (Levin et al., 2012). In these cases, immediate lock-in occurred through multi-year contracts in which individual home owners purchased solar panels with the promise of long-term payments. Once signed, the threat of mobilization and litigation that would accrue with any reversal created meaningful lock-in effects. Increasing returns followed as those who install solar panels earn increased economic benefits over time; self-reinforcing occurred as the costs of removing solar panels and investments constantly expanded over time especially as new entrants come into the market; and positive feedbacks occurred as new entrants reinforced the interests of the earlier purchasers of solar power (Schmidt and Sewerin, 2017).

Ecologically, the case of wolf reintroduction in Yellowstone National Park is an example of path dependency, wherein policy interventions originally sought to remedy negative ecological impacts—the chronic loss of plant communities and attendant ecosystem functioning due to heavy herbivory by wildlife species—that resulted from another path dependent policy enacted in the early 20th century to eradicate large predators from ecosystems throughout the USA. As in any complex ecosystem, the potential ramifying impacts of wolf reintroduction in the greater Yellowstone ecosystem were not completely reasoned through at first, and the insidious consequences are still unfolding decades later (Boyce, 2018). At the same time, given the political stakes to get the reintroduction approved and implemented, this policy is not easily reversed.

Parallel thinking can be applied to ecological and socio-political integration to achieve more ambitious greenhouse gas emissions reductions. Reasoning out alternative progressive incremental pathways can help reveal new features of a problem, and provide better knowledge of the functional relationships within a socio-political-ecological system to address it. Within ecosystems and political systems, there are numerous functional relationships to understand and include in a coherent policy framework. Our approach begins by recognizing that, say, an organism X may influence an ecosystem Y, which in turn influences a policy Z, which then, in turn, influences X and Y. Applying "forward reasoning", one can reason through different potential solutions dependent on this chain of influence to identify positive feedback loops that create durability, and thus reinforce the policy outcome for climate adaptation or mitigation.

We illustrate how one might apply a path dependent approach to policy aimed at sequestering and storing carbon in forests in a way that embraces ecological complexity. We underscore that the examples provided are meant to illustrate how a path dependent approach would unfold. Our intention is not to seek and prescribe solutions for a particular region. Rather we show how to advance a path dependency analysis approach by thinking much more about the complex path

Table 1
Four bottom-up path dependent triggers, descriptions, and examples of causal mechanism (Levin et al., 2012).

Lock-In	Immediately durable; legislation guaranteeing 20 year contracts for solar panels	Threat of mass mobilization and litigation from those who signed 20 year contracts
Self-Reinforcing	Reversal becomes more difficult over time; e.g. new solar farms	Expanded sunk costs as more and more consumers install solar panels
Increasing Returns	Increasing benefits over time; e.g. development of renewable energy technology	Increasing economic benefits as solar power owners enjoy reduced energy costs, and profits from the grid
Positive Feedback	Expanding support; e.g. feed-in tariffs emulated beyond original jurisdiction	Feed-in tariffs catch on, expanding populations covered to other jurisdictions that reinforce original norm

Table 2
Applying forward: moose hunting licenses as street-level change.

Lock-In	Recreational users are permitted to hunt more moose: immediate lock-in as a number of causal mechanisms; political support owing to increased recreational opportunities for hunters.
Self-Reinforcing	As economic benefits expand, the political costs of reversal become increasingly difficult, as constituencies will now expect, and want to maintain, moose hunting as part of their daily lives.
Increasing Returns	More recreational hunters will join in moose hunting, leading to increasing economic benefits.
Positive Feedback	Similarly, environmental groups who support conservation and carbon may, upon being confronted with dual impacts of biodiversity and carbon sequestration, form coalitions with hunting groups to expand this model elsewhere. This, in turn, could lead to the generation of new norms regarding forest management that would reinforce original support in boreal systems, while expanding to other regions.

dependent effects (lock-in, increasing returns, self-reinforcing and positive feedbacks) that could occur – often by pro-extractive policies which then trigger additional path dependent ecological effects, and encourage creative thinking about how to introduce policies that lower carbon emissions in durable and effective ways. To this end, we focus on policy and ecology of boreal forest management which, as a consequence of history, has resulted in the kind of path dependent effects by current forestry and industry practices in boreal regions, that become challenging but necessary to dismantle to implement forest carbon storage policy. Drawing on Levin et al., we first apply “backward looking” path dependency analysis, then “apply forward” to identify how a regional solution might be designed and implemented within political jurisdictions that encompass large areas of boreal forest.

We then outline the types of questions policy analysis would need to ask to nurture the trigger towards decarbonization. We illustrate that answering these questions means simultaneously reflecting on the social processes outlined by Levin et al. (2012) to address ecological problems, but also explicitly integrate into this approach ecological change processes as well. Hence, instead of treating negative changes in ecology as a problem path dependency analysis might be able to solve, we treat careful interrogation of the changes in boreal forest ecosystems owing to path dependent historical policies, as helping uncover potentially innovative low carbon policy triggers through the incorporation of highly complex science of boreal forest carbon emissions. In other words, whereas ecological knowledge has typically been used to tell us about the nature of the problem which affects policy responses, we argue that ecological science is as important for uncovering, and nurturing, low-carbon pathways. To accomplish such a goal, we also argue that an “ahistorical” focus on technology and prioritization of market and financing mechanisms has undermined reflections on other policy mixes that result from interrogating the interaction of ecology, policy, and society over time, which uncovers the role of path dependent processes fostering resource economies that resulted in higher carbon ecosystems, with potential for triggering lower-carbon economies.

2.1. Backward analysis: identifying the problems and causes

Examining forest management as a case example illustrates the gargantuan, complex “super-wicked problem” that is created when different policy sectors (resource extraction, wildlife management, species conservation, carbon mitigation) often develop in the absence of a central regulating authority. The result is a myriad of policy decisions affecting forest ecosystems, directly, or indirectly, being made without consideration of their interaction pathways. Siloed and tasked with only their particular resource sector in mind, these policy choices may end up working in opposition to each other. Collectively, they can create a landscape-wide "whack-a-mole" problem, in which timber harvesting and oil and gas extraction policies create conflicts with biodiversity conservation. Polices to fix the conservation problem created by resource extraction may in turn create conflicts with the carbon/climate problem (Nelson et al., 2009; Strassburg et al., 2010; Thomas et al., 2013). Hence, careful policy crafting is needed so that addressing one problem doesn’t create another (Nelson et al., 2009; Strassburg et al., 2010).

Management of boreal forests has long been developed in ways that tend to treat policy and ecological goals separately. Historical focused political economists (Innis 1933) found that, in the name of economic development, long-term “tenure licenses” would be granted to companies to committed to extracting timber and fostering employment in rural areas (Marchak, 1983). The resulting path dependent processes created communities whose economic and social livelihoods depended on maintaining these licenses. These long-term timber harvesting licenses were the trigger that not only created a myriad of social and political path dependent processes, but they also explain the durability and extent of industrial activity within the ecological system as well. Long-term tenure licenses, which were granted to private actors, created economic value by permitting resource extraction from the ecological system. Hence, “lock-in” occurred because once established, the social, economic and political costs of reversal were immediately high. For example, we would expect attempts to remove licenses being met by firms suing for compensation and community mobilization against the decision that could cause electoral defeat. Increasing returns occurred as extraction led to greater resource use and increased employment and tax revenue. Self-reinforcing processes further enhanced the stickiness of tenure licenses as the costs of reversal increased exponentially: compensation and political costs became higher over time as forest-dependent communities expanded. Positive feedback occurred through the creation of ancillary industries, which depended on maintaining the original intent of the policy, to facilitate long-term extraction via allocation of harvesting licenses (Innis, 1956).

The challenge for the Paris Agreement is that scientific evidence of changes in ecosystems resulting from path dependent policies aimed at enhancing forestry and other extractive sectors suggests conflicts with reducing climate emissions through forest management. Boreal forest ecosystems hold high strategic value for mitigating atmospheric carbon buildup. Much of the carbon taken up by boreal forests ends up in long-term storage as dead organic matter in the soil through normal ecosystem processes (Schmitz et al., 2014). Cool boreal soil conditions strongly limit soil microbes from breaking down organic matter and respiring it back to the atmosphere as carbon dioxide. Thus, boreal forests are able to store more carbon in live biomass and especially as organic matter in soils per unit area than most other places on earth — twice as much as tropical forests (Carlson et al., 2009). Estimates suggest that, with intentional ecosystem-based management, Canada’s boreal forests have a carbon potential equivalent to all of that nation’s annual CO_2 emissions from fossil fuel burning (Schmitz et al., 2014). However, for these processes to have an effect on Paris objectives, vast tracts of boreal forest must remain intact. Large tracts of land are needed because carbon storage is the result of ecological interactions among widely roaming predators like wolves and bears and their moose and deer prey (Fig. 1). Yet, path dependent forestry and other extractive operations run counter to these goals. The large open areas that resulted affected predator-prey relationships in the boreal forest because unlike caribou, moose populations thrive in more open spaces. The impacts on carbon sequestration and storage are multifaceted. First, moose consume vegetation, that triggers carbon loss from the ecosystem. In addition, the effects of this foraging can trigger multiplier effects on biogeochemical processes such rates of primary productivity and

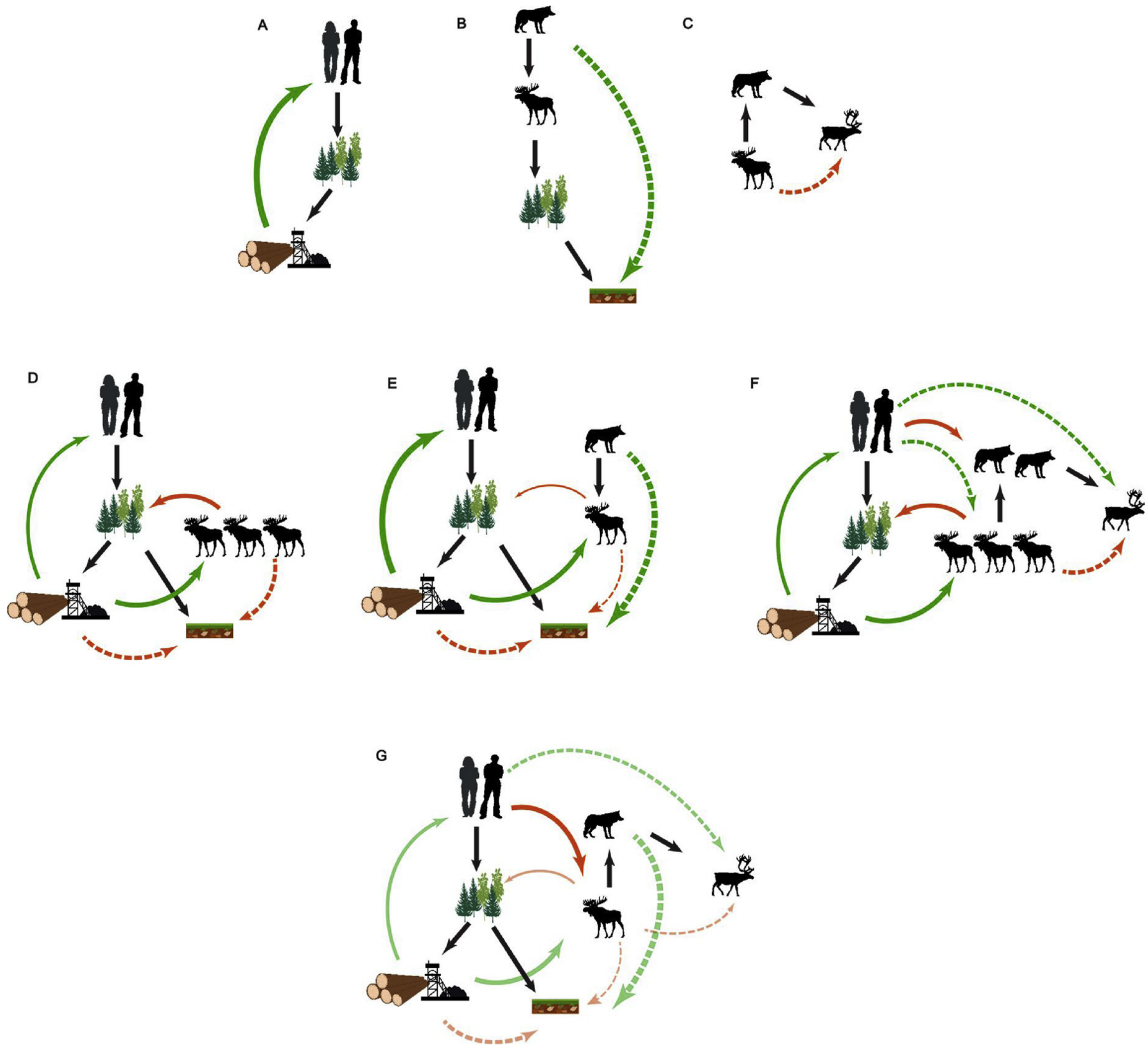

Fig. 1. Illustration of how consideration of different path dependencies of human engagement with an ecological system (in this case a boreal forest) can yield policy outcomes that can either be in conflict with, or enable reaching, multiple objectives of timber production, carbon sequestration and species conservation. The figure presents different interaction modules that can be systematically combined to understand emergent complexity due to multiple human and ecological interactions. Black arrows represent direct effects. Green and red curved arrows represent respectively positive and negative feedbacks that are direct (solid) or indirect (dashed). (A) The forestry sector concerns itself with interactions that sustain timber harvests and yields of timber and pulpwood. (B) The carbon sector concerns itself with conserving ecosystem processes that sequester carbon. (C) Wildlife and conservation concerns itself with protecting woodland caribou, a species threatened with extinction. (D) With no wolves forest damage would increase as forest thinning and regrowth after logging promotes moose population growth. (E) Keeping wolves in the ecosystem enhances tree abundance and soil carbon storage even with logging. (F) Culling wolves to protect caribou enables moose populations to grow and exacerbate forest impacts and loss of carbon storage. (H) The durable solution to meet multiple objectives is to increase human hunting pressure on moose. Images obtained through Creative Commons.

heterotrophic respiration of boreal ecosystems through selective browsing and by priming soil microbial decomposition that are disproportionately larger than would be expected based on moose abundance alone (Wilmers and Schmitz, 2016). The influence of moose through these pathways leads to an inverse relationship between moose density and ecosystem uptake of CO_2 in net primary production (NPP) and plant standing biomass, which eventually ends up in the soil carbon reservoir as shed leaves and branches (Schmitz et al., 2014). Thus, failing to consider moose effects on ecosystem biogeochemical processes could lead to overestimates of the ability of boreal forests to take up and store carbon by 40%–60% (Schmitz et al. 2018). Similar nature and magnitudes of animal effects on carbon cycling are increasingly being recognized as important, albeit complex, drivers of carbon dynamics in a variety of other ecosystems (Bakker and Svenning, 2018; Cromsigt et al., 2018; Schmitz et al., 2018).

Hence, timber extraction, as well as other ancillary industries (e.g., oil and gas development), can create conflicts with animal biogeochemical effects. Both extractive industries fragment large tracts of intact boreal forest. This development leads to increased forage production for moose and facilitates invasion by non-native species like white-tailed deer. Increased densities of both species supports higher wolf populations, which in turn increases predation on caribou, thereby jeopardizing the long-term viability of an important and already threatened wildlife species. This in turn has prompted conservation to push for policy actions to strengthen protection of caribou populations. Wolf culling has been the expedient policy solution to protect caribou (Hebblewhite, 2017).

However, this approach reinforces, rather than reduces, the complex impacts that forestry and other sectors had on punctuating higher carbon impact. Culling wolves will lead to loss of natural control over moose and deer densities, which in turn could cause decreased carbon storage in boreal forests ecosystem as moose abundances rise (Wilmers and Schmitz, 2016). This reduction comes about directly because the herbivores will alter the physical environment by browsing on photosynthetic tissue, and indirectly through reduction of NPP and tree growth that leads to reductions in forest canopy height and closure. This process can further result in lower humidity, warmer and drier soils, and hence CO_2 release via increased microbial respiration (Crowther et al., 2016) or increased frequency and intensity of forest fires (Schmitz et al., 2003). Therefore, culling wolves in boreal forests risks triggering ecological effects that could ultimately transform regions of the boreal forest from being net carbon sinks to net carbon sources, illustrating the importance of an a priori process that reasons the consequences of any single policy solution relative to the actions of different policy sectors within an inherently complex landscape.

2.2. Forward analysis: Developing path-dependent policy solutions that reconcile conflicts

2.2.1. Ecology component of the system: Moose in the carbon cycle

The story of carbon management in forest ecosystems is a complex one. This complexity contributes to the problem, wherein actions of different political agencies may lead to a conflict with policies to store carbon (Fig. 1A vs. 1B vs. 1C). We argue that application of path dependency analysis, combined with the treatment of policy and ecology as a single system, allow us to engage wildlife policy to consider a carbon dividend. However, herein also lies a conflict between human control of predators (wolves) to protect a threatened species (caribou), and the release from predator (wolves) control of another species (moose) whose impact on the forest could mitigate and increase carbon storage (Fig. 1E, 1F, 1G). Reconciling the conflict requires thinking about and enlisting additional leverage points in the system that can reverse the rise in moose populations. One solution that emerged from integrating the insights above, along with our decades-long research on path dependency in punctuating both political and ecological systems, led us to reflect on the broad sources of path dependency that different types of policy mixes might trigger. Consistent with the Paris Agreement, and path dependency analysis targeting "easy to change, but hard to reverse" triggers, we were motivated by research on "street level" bureaucrats (Meyers and Vorsanger, 2003; Sabatier, 1986) who can often unleash from local authority society-wide transformation. Doing so led us to identify drawing on hunting policy not just for game and trophy hunting, but as a new means of enhancing carbon sequestration with potentially powerful path dependent effects. Herein lies our additional leverage point: hunting moose could be considered a way to resolve conflict among policy sectors and drive carbon into the soil (Fig. 1H).

This leverage point comes about from several considerations of how different path dependencies of human engagement with an ecological system (in this case a boreal forest) can yield policy outcomes that can either be in conflict with, or enable reaching, multiple objectives of timber production, carbon sequestration and species conservation. First (Fig. 1A), the forestry sector concerns itself with sustaining timber harvests and yields. Humans directly affect forests (tree abundance) through harvesting that yields timber and pulpwood. The carbon sector (Fig. 1B) concerns itself with ecosystem carbon sequestration by preserving forest ecosystem processes. In this case, wolves can trigger a cascade of effects by controlling moose abundance that in turn reduces impacts on forests that in turn enhances carbon storage in boreal soils which can promote sequestration. Hence, wolves have an indirect beneficial effect on soil carbon storage (Schmitz et al., 2014). Wildlife management and conservation (Fig. 1C) concerns itself with protecting woodland caribou, a species threatened with extinction. Wolves interact directly with moose and caribou. Moose have an indirect negative affect on caribou mediated through their interaction with wolves: higher moose abundances support higher wolf abundances, which puts predation pressure on caribou, called apparent competition between moose and caribou (Hebblewhite, 2017). Often management culls wolves from the ecosystem to protect caribou. The consequence of such policies has ramifying effects. While logging still provides beneficial wood products for humans, forest thinning and regrowth after logging promotes moose population growth that, in the absence of wolves, will have negative feedback impacts on forest biomass and soil carbon storage. Thus, keeping wolves as part of the ecosystem (Fig. 1E) maintains ecological interactions that lower the negative impacts of moose on tree abundance and soil carbon storage. Moreover, culling wolves to protect caribou (Fig. 1F), enables moose populations to grow and exacerbate moose impacts on forests that are maintained by the positive effects of logging. It also allows wolf populations to rebound quickly from culls. One solution to meet the multiple objectives of sustaining logging, protecting caribou populations, and storing carbon in boreal soils, is to increase human hunting pressure on moose to create a feedback that controls the increase of moose population size (Fig. 1G).

Hence, the first part of this argument integrates two different boreal epistemic communities, challenging conventional thinking that carbon sequestration in forests merely requires managing tree production. This then leads us to the heart of our argument: that integrating ecological and political systems as reinforcing and path dependent may lead to the development of new approaches and ways of examining the same regions, problems, and potential solutions. While significant carbon sequestration through trees themselves might be appropriate for tropical systems, carbon uptake is different for boreal forest ecosystems that follow a 60-year disturbance regime (Schmitz et al., 2014). In the case of the boreal forest, most carbon is stored within soils rather than trees themselves (Schmitz et al., 2014). A different mechanism needs to be considered to drive carbon sequestration in this system, namely, management of moose populations to keep them from increasing and damaging trees and altering biogeochemical processes (Fig. 1B). This mechanism stems from ecological understanding that carbon in boreal forests is steered into soils consequent to wolf-moose predator-prey interactions (Schmitz et al., 2014). Furthermore, this mechanism is idiosyncratic to the boreal forest, an illustrative example of a regional ecosystem characteristic (Wilmers and Schmitz 2016). Because of the regional ecological context, this policy approach has the potential to become durable as a means of carbon sequestration. In this case example, wildlife management becomes an ecological lever to store carbon.

Hence, if these ecological models are correct they suggest that managing moose populations in the boreal system in particular can serve to increase carbon storage. In the absence of being able to reduce extractive sectors (which are themselves now quite path dependent), reducing moose populations would lead to a simultaneous punctuation toward lower carbon emissions, levels much closer to historical outputs of predator-prey interactions before the introduction of logging (as well as other sectors such as mining and oil and gas).

How might moose populations be reduced to create policy stickiness so these efforts could contribute to help Canada meet its long-term commitments to the Paris Agreement? We now turn to path dependency framework applied within policy studies to reflect on innovative solutions.

2.2.2. The policy component of the system: Moose hunting licenses as street level bureaucrats

We theorize that instead of a top-down national or provincial legislative solution to managing moose populations, one potential "easy to pull", hard to reverse lever can be identified in the form of hunting licenses triggered by "street level bureaucrats" (Meyers and Vorsanger, 2003). The formal mechanisms can be coordinated through the allocation of hunting permits that could trigger a cascade of causal processes creating immediate lock-in, self-reinforcing processes, increasing returns and positive feedback. We expect that immediate lock-in would occur if managing hunting permits could create coalitions of environmentalists and rural hunting communities. Political science research tell us that when disparate groups support the same intervention but for different reasons, it creates political coalitions that are so strong they create durable policies (Bernstein and Hoffmann, 2018; Meckling, 2011). Second, the triggering of hunting licenses could lead to creating self-reinforcing processes as, over time, more and more rural communities would engage in hunting moose, rendering the political costs of reversal more difficult over time. Third, increasing returns would expand as communities benefited from moose protein, and associated hide and other products that might be used to fashion clothing and other household needs. Positive feedback would also be nurtured as we would expect diffusion of this hunting license model, as environmental groups and rural communities would want to emulate the climate and cultural benefits of the policy.

Hence, applying forward reasoning leads to theorizing that management decisions concerning hunting licenses consistent with the science of predator-prey relationships offers a potential mechanism to trigger transformative change to increase carbon storage in boreal forests. While not a climate panacea, hunting licenses, owing to the decentralized authority of “street level” bureaucrats, are arguably easier to change, and more politically salient, than other types of more direct climate reductions, such as carbon taxes or subsidies that may face obstacles in gaining necessary political support.

Hunting is one illustrative approach we can take towards the integration of ecology and policy sciences for climate mitigation. Incorporating our causal framework, we provide an example of a wildlife management regime becoming a climate policy with moose hunting in boreal regions. This example is now a leverage point that considers both ecology and political science. We arrived to the conclusion that moose hunting can control biogeochemical processes and may contribute to long-term carbon uptake by considering interactions between these different disciplines.

While our case study assumes logging as a given in this situation, we emphasize that there is also potential for change in the current logging status quo. Moreover, our argument is not that hunting policies should be pursued in the place of transitioning away from fossil fuels and toward renewable energy, but rather that this integrative approach can help us devise additional, creative triggers for climate change mitigation. By empirically applying interactions between the different climate sciences, we open a creative space to propose novel solutions.

3. Broader implications

In this paper, we suggest integrating different environmental disciplines to reason through complexity, and identify an approach that may lead to more innovative and durable climate change solutions. We argue especially that applying a path dependent framework helps empirically illustrate interactions in ecological and policy systems. This approach fosters increased collaboration and integration between natural and social sciences to develop new or improved triggers for climate change mitigation. This backward process furthermore allows us to identify existing constraints, then use forward reasoning to evaluate available options that address multiple conflicting goals. In isolation, these different goals may conflict; in this approach, they are considered to be part of the same system.

We use the boreal forest ecosystem as a case example of how such an approach may be applied. While we do not advocate for any particular management approach per se, the example of moose hunting can be used to think through novel approaches to carbon sequestration. We are not saying that hunting as a replacement for wolf control is a silver bullet – indeed, it wouldn’t necessarily work in grasslands (Wilmers and Schmitz, 2016); rather, our analysis of the boreal forest ecosystem as an entwined policy and ecology system demonstrates how we could get counterintuitive, and heretofore unconsidered, solutions that could help make a difference in climate change mitigation.

Such an integrated framework creates opportunities for high-emitting countries to take responsibility for their greenhouse gas emissions within their own political jurisdiction. In the case of the boreal forest, we broaden understanding and application of forest sequestration beyond traditional carbon management in tropical systems in developing countries to include ecosystems in Arctic nations such as Canada, the United States, and Russia, that together account for a significant portion of worldwide greenhouse gas emissions. This regional focus helps mitigate some of the concerns of forest management projects, such as leakage, permanence, and monitoring and accounting, which frequently arise with REDD + projects (Visseren-Hamakers et al., 2012). This approach is a lever that domestic actors can pull to bring action down from the global sphere to their specific regions. Hence, it is practical when considering international agreements and global calls for action on climate change to implement a causal framework so that we may better understand regional interactions between the natural and social sciences.

Current policy prescriptions for climate change frequently fail to incorporate all relevant ecological dynamics at play, yet also fail to reflect on designing policies not simply to directly target the problem in question, but to do so in a way that makes irreversibility difficult. By engaging collaborative processes that focus on integrating these different social and ecological disciplines, we argue that policymakers will be able to develop more creative, durable, and effective climate policies that would otherwise be left on the table. To be sure, any effort to do so requires some type of “playbook” that institutionalizes these diverse knowledge sources, and identifies the forward-looking multiple steps that would need to be undertaken and coordinated (Cashore et al., 2019). With potential in helping governments meet their climate objectives, our approach not only reinforces burgeoning applied efforts to trigger path dependent low carbon economies, but also calls for much greater integration of historical changes within interacting policy and ecological systems.

Competing interests

The authors declare no competing interests.

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