AGENDA

Agriculture, Forests, Fisheries, Rural Communities and Tribes Work Group

November 2, 2017
1:00 PM – 3:00 PM
Hearing Room 50 State Capitol (ground level)

AGENDA

- Welcome and Introductions
- Work Group Discussion of Policy Questions
- Public Comment
- Next Steps
- Adjourn

This meeting will be livestreamed. You may access the livestream at: *https://www.oregonlegislature.gov/citizen_engagement/Pages/Legislative-Video.aspx.* You may also participate in this meeting by teleconference by calling 1--877-848-7030, meeting # 7714152.

Meeting materials are posted at: *https://www.oregonlegislature.gov/helm/Pages/affrct.aspx.*

Policy Questions to Prepare and Discuss at November Work Group Meetings

(11/2/17)

Senate Bill 1070
Policy Questions

At the upcoming work group meetings, each work group will discuss the policy questions below. Each section has been assigned to a work group, however some questions are likely to be discussed in multiple work groups. Thank you for reviewing the document and coming prepared with your feedback.

OFFSETS – AGRICULTURE, FORESTS, FISHERIES, RURAL COMMUNITIES, AND TRIBES

Percentage of compliance obligation that can be met with offsets?	**SB 1070**: 8% cap, allows lower percentage in certain areas. **Proposal**:
Restrictions on offset project location?	**SB 1070**: Be located in the United States or a country with which EQC has entered an agreement for administering a carbon pollution market **Proposal:**
Should aggregation be allowed?	**SB 1070**: Not addressed **Proposal:**
Principles that govern protocol development?	**SB 1070**: Not addressed **Proposal:**
Role of ODA and ODF in protocol development?	**SB 1070**: Not addressed **Proposal:**

POINT OF REGULATION – UTILITIES AND TRANSPORTATION

Utilities POR?	**SB 1070**: Not specified **Proposal**: first jurisdictional deliverer (FJD)
Natural Gas POR?	**SB 1070**: Not specified **Proposal:** Load serving entity (LSE)
Industrial Sources POR?	**SB 1070**: Not specified **Proposal:**

ALLOWANCE DISTRIBUTION AND CONSIGNMENT – UTILITIES AND TRANSPORTATION

Are allowances distributed to utilities free of charge for consignment?	**SB 1070**: Yes **Proposal**: Establish set of principles in legislation to guide distribution
Should allowances distributed free of charge to utilities be consigned to auction?	**SB 1070**: Yes **Proposal:**
Should allowances be distributed free of charge to covered COUs? If so, how should revenue investments be overseen?	**SB 1070**: Allowed but not required. **Proposal:**

EMISSIONS-INTENSIVE, TRADE-EXPOSED INDUSTRIES (EITEs) – REGULATED ENTITIES

Criteria to identify EITE's?	**SB 1070**: No criteria. Directs EQC to hire or contract with 3rd party to provide data and analysis to identify leakage risk **Proposal**:
How are allowances allocated to EITEs?	**SB 1070**: Requires free distribution to address leakage and as determined necessary by EQC. **Proposal:** Establish principles governing distribution formula?
Should there be principles/ criteria for whether allowances are full or partial; on a declining schedule over time; and subject to review?	**SB 1070**: No criteria **Proposal**:

COST CONTAINMENT MEASURES – REGLATED ENTITIES AND UTILITIES AND TRANSPORTATION

Linkage	**SB 1070**: Directs program to be developed in a manner necessary to pursue linkage. **Proposal**:
Price containment reserve	**SB 1070**: Requires DEQ to place a percentage of allowances in reserve as directed by EQC to assist covered entities in event of unanticipated high costs of compliance instruments. **Proposal:**
Banking	**SB 1070**: Requires EQC to adopt rules to specify allowance holding limits **Proposal:**
Price floor	**SB 1070**: Requires EQC to adopt rules to set an auction price floor and schedule for floor price to increase **Proposal:**

REVENUE INVESTMENTS – ENVIRONMENTAL JUSTICE/JUST TRANSITION

Definition of "impacted communities" and "economically distressed areas"	**SB 1070**: SB 1070 language **Proposal:** (12) Communities experiencing disparate impacts of climate change or "Most Impacted communities" is defined by an analysis of racial and socioeconomic demographics, overlaid with environmental and public health data by census tract. In identifying 'Most Impacted Communities" the methodology must consider indicators including, but not limited to, the following: (a) Above the state average percentage nonwhite population; (b) Above the state average percentage of the population has an income below 200% of the federal poverty limit; (c) Above the state average percentage of the population over 25 years of age without a high school degree/diploma; (d) Above the state average percentage of the labor force over 16 years of age are not employed;

	(e) Above the state average percentage of the population are over 65 years of age or under 10 years of age (g) Above the state average cancer risk, with cancer risk being defined as an estimate of an individual's cancer risk as the result of a lifetime of exposure to a range of point and mobile source air toxins within a geographic entity (h) Above the state average respiratory hazard risk, with respiratory health risk being defined as an estimate of adverse health effects identified by length of time and concentration of exposure to a range of point and mobile source air toxins within a geographic entity (i) A Native American population on a reservation or tribal trust lands of a federally recognized tribe in Oregon, particularly those reliant on subsistence lifestyles.
Criteria for revenue investments? Including use of consigned allowance revenue?	**SB 1070**: Umbrella requirement: reduce greenhouse gas emissions consistent with statewide greenhouse gas emissions levels and to promote adaptation and resilience in the face of climate change. See attached diagram for additional criteria. **Proposal**:
Method of revenue distribution?	**SB 1070**: Grants. See attached diagram. **Proposal:** Proceeds can be distributed through both grant based programs and automatic allocation.
Investment governance and oversight roles and responsibilities	**SB 1070**: See attached diagram. **Proposal:**
Should revenues be utilized in part to incentivize sequestration and adaptation?	**SB 1070**: Revenues can be used for purposes of the Act, which is to reduce greenhouse gas emissions and to promote adaptation and resilience by the state's communities and economy in the face of climate change. **Proposal:**
Should regulated entities be allowed to be the recipients of program grants or other funding to help them comply?	**SB 1070**: Not addressed **Proposal:**

CAP-AND-INVEST PROGRAM GOVERNANCE – ALL

Which agency administers this program?	SB 1070: Primarily DEQ, with role for ODOT and Business OR in grant distribution Proposal:
Are there appropriate accountability measures?	SB 1070: The Greenhouse Gas Cap and Investment Program Oversight Committee is required to study the implementation of the program, make recommendations and conduct other necessary studies to provide implementation oversight. Proposal:

Senate Bill 1070 (2017)

Governance of Auction Revenues

STATE TREASURY

All SB 1070 funds must be used to reduce greenhouse gas emissions and to promote climate change adaptation and resilience by Oregon s communities and economy.

State Highway Fund *§14,§11*
Climate Investments Account

Oregon Climate Investments Fund *§15,§11*
(85% of general auction proceeds)

Just Transition Fund *§19,§11*
(15% of general auction proceeds)

Consignment Proceeds *§11,§13*
Allowances distributed free-of-charge must be consigned to the state for auction

ODOT

Distribution Requirements

- At least 20% to projects geographically located in impacted communities
- At least 20% to projects that otherwise benefit impacted communities
- Meaningful share to projects that involve businesses owned by women and minorities
- Funding preference to projects that result in greatest GHG reductions

Rulemaking: ODOT *(§38)*

Climate Investments in Impacted Communities Advisory Committee

Consult and make recommendations on investments that benefit impacted communities *§17*

DEQ

CLIMATE INVESTMENTS GRANT PROGRAM *§16*

Distribution Requirements

- At least 50% to projects geographically located in impacted communities
- At least 40% to projects geographically located in economically distressed areas; emphasis placed on job creation, job education, and training opportunities
- Funding preferences specified *(§16(5)(a-g))*

Rulemaking: EQC in consultation with EJ Task Force, Indian tribes, PUC, ODOE, ODOT, OHA, other interested agencies, and Advisory Committee

Climate Investments Grant Committee

Reviews grant applications and makes funding determinations; governor-appointed, subject to senate confirmation

Business Oregon

JUST TRANSITION GRANT PROGRAM *§20*

Distribution Requirements

- Support economic diversification, job creation, job training, and other employment and mental health services for Oregon workers and communities that are adversely affected by climate change or climate change policies

Rulemaking: Business Oregon in consultation with Advisory Committee

Just Transition Grant Committee

Reviews grant applications and makes funding determinations; governor-appointed, subject to senate confirmation

Advisory Committee *§7*

Provide advice from diversity of interests

Electric Companies & Natural Gas Utilities

Distribution Requirements

- Must serve to stabilize and reduce energy bills
- Prioritize low-income residential customers

Rulemaking: PUC in consultation with Advisory Committee

Consumer-Owned Utilities

Distribution Requirements

- None specified

Rulemaking: DEQ

Types of Auction Revenues

- State Highway Fund Revenue *(Or. Const. Article IX, § 3a)*
- Other Funds Revenue
- Consignment Revenue

Legislative Policy and Research Office, September 2017

Offsets Offer Impact, Real Carbon Reductions in Natural Working Lands (Penrith, The Climate Trust)

11/2/17

THE CLIMATE TRUST
INVEST WITH IMPACT

November 2, 2017

Offsets Offer Impact, Real Carbon Reductions in Natural Working Lands

By Sean Penrith, Executive Director for The Climate Trust

The discussions around Oregon's proposed cap and invest bill (SB1070), slated for the short session in 2018, continue unabated and common misperceptions abound. To the credit of the sponsors of the bill—Representative Helm and Senator Dembrow—they have engendered the important dialog on elements in the bill between diverse stakeholders by way of the various working groups they have established.

The Climate Trust was invited to participate on the Agricultural, Forests, Fisheries, Rural Communities, and Tribes working group, to review and make recommendations on specific components of a cap and invest program for Oregon. The offset mechanism contained in SB1070 has stimulated a robust discussion. Environmental justice proponents have submitted comments calling for the prohibition of offsets. I attempt to outline points that address four questions posed to the working group that include offset limits, project location guidelines, aggregation, and protocol development while weaving in our general support for a well constructed offset mechanism for our state.

The *"Guiding Principles and Recommendations for Policy and Funding Decisions"* report, compiled by the Climate Justice Working Group, has been circulating with environmental justice advocates suggesting that it may help inform the policy discussions currently underway in the state. I read the report with interest. The forestry section of the paper addressed financing opportunities, pointing out that, "*The state must seek funding opportunities from private and public sources to make meaningful climate adaptation investments. Sectors should implement actions that can simultaneously reduce GHG emissions and also make vulnerable communities more resilient."* It struck me that that the offset mechanism achieves that very laudable aim; it attracts private capital to create meaningful climate investments that achieve real greenhouse gas reductions, while simultaneously adding resiliency in terms of improved co-benefits.

The chair of the Senate Environment & Natural Resources committee, Senator Michael Dembrow, summarized the intent of the cap and invest bill, calling out that SB1070 included cost controls and the harnessing of market forces, the ability to link to the Western Climate Initiative (WCI), and offered opportunities for investments, especially in rural economies. Again, check! The offset mechanism is by design a cost containment provision and allows for inter-jurisdiction trading of verified offset credits between partners in the WCI. Further, the offset market attracts private capital to carbon reduction offset projects (diary digesters, forest protection, grassland conservation, etc.) that tend to be primarily located in rural regions. We need this. There are just not sufficient public funds to drive the reductions we need, especially in our natural working lands.

We are strong advocates that the percentage of compliance obligation that can be met by offsets remain at the 8% limit set in SB1070. Certainty in significant, long-term demand for offsets will mobilize private capital into land-based greenhouse gas reduction projects. A reduced offset limit sends a signal of uncertainty to private investors, limiting interest in financing agricultural and forestry emissions reduction. Increasing allowance funding for forest and soil sequestration activities should never be viewed as an equivalent replacement of the offset mechanism. Direct reinvestment of auction revenue is essential, especially for very small or difficult to quantify projects, but cannot match the pace and scale of investment the offset market creates. The offset market can motivate agricultural and forestry greenhouse gas reductions rapidly and at greater scale than auction fund reinvestment alone because it sends a long-term price signal that can be depended upon, makes payments for verified reductions rather than anticipated reductions, and focuses on the most cost-effective reduction opportunities. We have detailed why the offset market leverages more private finance than the programs we have seen from California's Greenhouse Gas Reduction Fund in this brief. The strong demand for offsets created by an 8% limit is key to leverage private finance to achieve the emission reductions we need from agriculture and forestry.

The intersection of carbon reductions and air quality was hotly debated in California. Their solution was to pass AB398 that extended the cap and trade program to 2030 along with the companion bill AB167 that expressly protects communities from air pollution from both mobile and stationary sources. DEQ's report, *"Considerations for Designing a Cap-and-Trade Program in Oregon,"* recognizes this same key issue, pointing out that, "The 'trading' features of the program, which help keep costs of compliance lower, also result in uncertain decline in GHGs and co-pollutants from individual facilities." DEQ does state that they already have long-standing air quality enforcement programs to manage our state's largest source of pollution and that they are undertaking reforms of their air toxics regulations to address public health. I would have to agree that, similar to the conclusion arrived at in California; we should separate out our carbon emission reduction ambitions from the focused efforts of air quality control. In DEQ's words, their existing programs "may be better suited to address sources of localized health concern."

Oregon's cap and invest bill offers some flexibility when it comes to the degree that offsets can be used for compliance. The bill contemplates an offset limit of 'no more than' 8% for covered entities and allows this to be further restricted should it be warranted based on the proximity of the emissions source to an impacted community. There has been some discussion that Oregon must follow California's lead and adopt a 4% limit that AB398 calls for post-2020 in order to satisfy linkage requirements. That is not accurate.

Senate Bill 1018 (Committee on Budget and Fiscal Review, Ch. 39, St. 2012) requires a demonstration of stringency before future linkages with California can occur—that "the jurisdiction with which the state agency proposes to link has adopted program requirements for greenhouse gas reductions, including, but not limited to, requirements for offsets, that are equivalent to or stricter than [California's]." These parameters include being real, permanent, quantifiable, verifiable, enforceable and additional, but should not include jurisdictional-specific geographic or numeric criteria. Thus, additional jurisdiction-specific criteria do not impact the "stringency" of other programs. The recent linkage of California's program to Ontario, Canada was not based on the newly introduced restrictions on the program. Potential future partners considering linkage, such as Oregon, should likewise not be subject to the direct environmental benefits provision or lower offset usage provisions of California's AB 398. The key to a successfully linked market-based program is maintaining consistent environmental integrity.

We have a strong interest in enabling smaller landowners to participate in the carbon market based on the passage of SB1070. California's Air Resources Board (ARB) has implemented a number of constraints that limit project aggregation for the California market, a central one being the invalidation rule that delivers the liability to buyers. Oregon is not bound to follow suit. Oregon can support aggregation by avoiding a similar invalidation rule found in California. Offset protocols in the voluntary market that allow for aggregation already exist. The Climate Trust is currently using the Climate Action Reserve grasslands protocol to aggregate three distinct parcels of land in Wallowa County so it can be managed as a single offset project. There are other protocols that also facilitate aggregation among small forest landowners and farmers.

The benefit of allowing aggregation is that it provides access to the offset market for smaller landowners who may be unable to participate individually due to the costs associated with developing and managing an offset project. It is noteworthy that Ontario's offset guidelines allow for project aggregation. Should SB1070 be implemented, we will see carbon prices for verified offset reductions in the high teens and low twenties range. According to the evaluation by Greg Latta at the University of Idaho (Forest Economics) over the first ten years of a cap and trade program, forest carbon projects in the Western Cascades would generate between $667 million and $1.93 billion of offset credits. This will offer attractive returns to smaller landowners wishing to deliver real emission reductions in return for revenues.

In terms of Oregon's potential for participating in the offset market, we should take note of a recent Stanford paper, "Forest carbon offsets partner climate-change mitigation with conservation." The study reviewed existing forest carbon projects that have participated in the California cap and trade market and notes, “The national distribution of projects generally matches the distribution of private forestland in the U.S., with the notable exceptions of Oregon (no projects) and Washington State (one project). Sustainable forest management rules mandated by the offset program are stringent and may reduce the fraction of projects in regions with less stringent versions of such rules.”

There is understandable interest in limiting offset projects to Oregon only. As implementers of Oregon’s CO2 Standard for new energy facilities over the past 20 years, we at The Climate Trust, have experienced pertinent lessons first hand. Our take is that there is an enormous opportunity to develop suitable offset requirements in Oregon that allow us to take advantage of the broader linked market, as opposed to taking the isolationist approach of Oregon-only projects as some have touted.

Oregon’s forests are eligible to participate in California, Quebec and Ontario’s linked carbon market—but to do so, they must qualify to generate credits under the protocol created by ARB. As the study above alludes to, potential forestry projects in Oregon have had a very difficult time conforming to the “sustainable forest management” criteria required by the protocol, which generally restricts forest management practices to those allowed under California Forest Practice Rules.

As the California-oriented forest protocol demonstrates, when we let other states create the rules, Oregon is left out of an emerging $5 billion market for carbon sequestration. By moving forward with a cap and trade system, Oregon has an opportunity to draft its own forest protocol to ensure reductions are real, permanent, quantifiable, verifiable, enforceable and additional.

Protocol development under SB1070 should adhere at all times to the environmental integrity of the cap and enable linkage with other jurisdictions. All protocols must ensure offsets are real, quantifiable, permanent, enforceable, additional and verifiable. The good news is that the leading registries in the country have conducted thorough and diligent work in this regard. American Carbon Registry’s (ACR) process for protocol development includes a public comment period and a blind scientific peer review. ACR details the recommendations for boundary selection, greenhouse gas accounting, and a host of other considerations when designing the offset mechanism and supporting protocols. Climate Action Reserve offers a full program manual that can be accessed to help inform relevant protocol adoption in Oregon. A task force dedicated to providing guidance to the state in developing and approving offset protocols would go a long way to embracing these best practices and edit them for Oregon benefit.

The largest pall cast by the Clean Development Mechanism (CDM) market resulting from the European Union Emission Trading Schemes (ETS) was on the concept of additionality; the determination that the property of an activity must be additional and beyond business as usual. CDM projects are somewhat infamous, proving to be questionably additional. Those lessons have been learned by carbon pricing proponents and program design architects that followed the EU ETS experience.

California has learned from and improved upon its program design with performance standards for assuring additionality. The additionality factor of existing protocols in California was challenged in 2012. In January 2013, the San Francisco Superior Court ruled that the ARB had "used its experience, expertise, and judgment in arriving at the appropriate methodology to determine additionality … based on extensive research, stakeholder input, public input and fact-based analysis." This decision was subsequently upheld by the Court of Appeal, which the California Supreme Court let stand. In short, while these issues are nuanced and complex, they have been considered and thoroughly tested. There is no compelling case that the legislature, ARB, and the courts all got it wrong before.

The sponsors of SB1070 are asking the right questions and, from all accounts, paying close attention to the feedback they are receiving. I hope this delivers a solid carbon-pricing program for Oregon and for our WCI partners.

Oregon Carbon Pricing Policy; A Role for Natural and Working Lands (Sustainable Northwest; Pinchot Institute for Conservation; Ecotrust; The Nature Conservancy; The Climate Trust)

11/6/17

To: Work Group on Agriculture, Forests, Fisheries, Rural Communities, and Tribes
From: Sustainable Northwest, Pinchot Institute for Conservation, Ecotrust, The Nature Conservancy, and The Climate Trust
Re: Oregon Carbon Pricing Policy: A Role for Natural and Working Lands
Date: November 6, 2017

The value of natural and working lands to Oregon's environment, economy, and communities cannot be overstated. Not only are they the economic engine for Oregon's rural communities, they have the potential to make a significant contribution to reducing and mitigating climate change. Carbon pricing legislation, such as Senate Bill 1070, represents an important opportunity to address challenges facing rural Oregon and its landscapes, reduce atmospheric greenhouse gas (GHG) emissions and adapt rural communities and economies to the unavoidable impacts of climate change.

Not only does a unique opportunity and diverse natural infrastructure exist, but there is a pressing ***need*** to harness our natural and working lands to reduce greenhouse gases. While there have been significant advances in emission reduction technologies and clean energy, meeting our reduction goals without natural climate solutions will be extremely challenging and potentially have negative economic consequences. Recognition of and investment in these resources can expedite the emission reduction process, mitigate unintended economic effects, and support equitable participation and benefits for rural communities. Working lands represent nearly 20% of our emissions budget and activities to sequester carbon are relatively inexpensive, with the potential for significant additionality.

Despite this urgency and the integral role that natural and working lands play in Oregon's carbon cycle (see Appendix B), they are underrepresented in Senate Bill 1070. To achieve ecosystem and community resilience and a comprehensive climate smart economy, investment in natural and working lands must be defined and included in carbon pricing legislation.

Why invest in natural and working lands?

✓ **Achieve additional GHG emission reductions from uncovered sectors**
Although working forests and agricultural lands are not covered sectors in carbon pricing legislation, they are nonetheless some of the largest carbon sinks in Oregon and have tremendous potential for increased mitigation. Farms, forests, and ranches can adopt climate smart practices that both store carbon in biomass and soils, help these lands adapt to the effects of climate change, and improve productivity. SB 1070 can also encourage offset protocols that encourage aggregation allowing smaller landowners to pool their parcels into a single project and take advantage of economies of scale.

✓ **Leverage federal match funding**
Land management planning and conservation practices are often supported through the Conservation Title of the Farm Bill. Accessing these federal programs and funding often requires a source of non-federal match, including state investments. A new source of non-federal funding could significantly leverage Oregon's slice of the Farm Bill, benefiting family owned forests, farms, and ranches, and the natural-resource based economy as a whole.

- ✓ **Provide overlapping conservation benefits and values**
  Revenues from an Oregon GHG pricing policy can be invested in ways that not only enhance carbon sequestration and storage, but provide ancillary benefits to water resources, air quality, and wildlife. Proactive, voluntary approaches are also more cost-effective to the state and landowners, as front-end investments are less expensive than future regulatory actions that may be required to recover from environmental emergencies or compliance obligations.

- ✓ **Drive innovation and new markets**
  As climate smart practices are adopted, new business opportunities emerge to promote water efficiency, innovation in forest products, and ecosystem service payments. Furthermore, family-owned working forests, farms, and ranches face unique financial and management challenges. Increasingly, these lands are being sold out of family ownership or developed—eroding certainty about the natural resource and climate related benefits they will provide. New revenue models can provide alternatives to the sale and development of these landscapes that would result in release of captured carbon and the elimination of future sequestration potential.

- ✓ **Improve climate resiliency**
  Not only do natural and working lands store and sequester carbon to help slow future changes in climate, they can also provide adaptation services to help mitigate effects that cannot be prevented. Carbon pricing policies and strategic investments can support existing and promising mechanisms to make the state's communities and lands resilient to climate change. This includes water storage and delivery, wildfire risk reduction, and wildlife habitat enhancement.

- ✓ **Support equitable program design and benefits**
  Rural and tribal natural resource communities are some of the first demographics to feel the effects of climate change and climate change policies, and will be perhaps the most significantly impacted due to short and long-term changes in the geographies where they reside and corresponding effects on livelihoods. Investments in natural and working lands can help equitably distribute the benefits of a cap and trade system to underserved rural, resource dependent communities. Strategic investments can promote adaptation, sustain natural resource economies, and generate new revenue and value streams to support transition to climate smart practices.

<u>The role for Oregon natural and working lands in cap and invest</u>

Climate smart investments in natural and working lands emphasize synergies between increasing productivity and incomes, while implementing climate change adaptation and mitigation through traditional and innovative strategies. In forestry and agriculture, the approach relies on management practices that increase net carbon stores while improving overall ecological health. ***Incentive-based emission reductions can work in conjunction with an offset program, allowing for a broader base of participation from a range of landowners***. Offsets provide a suite of benefits and outcomes that have been extensively documented, but must be carefully planned. To this end, it is important that SB 1070 promotes aggregation of smaller lands into larger offset projects and is designed to maintain transparency and safeguards equivalent to those for larger offset projects. Such policies can help smaller lands overcome barriers associated with offset project development and achieve economies of scale. In addition to promoting policies that enable smaller landowners to participate in the offset market, climate smart natural and working lands incentive payments and other direct investments can help family forests and farms on considerably smaller acreages, and distribute returns across Oregon's agricultural and forest sectors. **This paper focuses predominantly on opportunities for investments of program revenue derived from the sale of emission allowances, with offsets addressed sufficiently elsewhere.**

At the state level, California is aggressively pursuing a strategy of incentive payments via its Healthy Soils Initiative. California, however, through its offset invalidation requirements has created an impediment to small landowners from entering the offset market by preventing aggregation. Oregon can avoid a similar outcome, by ensuring invalidation is not a part of SB 1070's policy on offsets. At the Federal level, the U.S. Department of Agriculture (USDA) has advanced this approach through its Building Blocks for Climate Smart Agriculture and Forestry in the 2015 Climate Action Plan. Measurable goals tied to each building block are linked to key actions and specific conservation practices and corresponding Farm Bill programs identified by the USDA Natural Resource Conservation Service (NRCS) and USDA Forest Service.

A more robust and inclusive Oregon legislative package would include explicit recognition of the climate change mitigation benefits and the need for adaptation on Oregon's natural and working lands, accompanied by appropriate programmatic investments. Authorizing and guiding language in statute would be fairly general (see Appendix A), but the corresponding rulemaking process would articulate a suite of natural resource related program priorities and investments.

Examples of eligible projects could include:

- Direct practice or performance payments to forest and agricultural landowners for implementing actions that reduce and sequester greenhouse gases and achieve climate smart conservation. These could be termed lease agreements or practice specific actions similar to the California Healthy Soils Initiative or USDA NRCS programs.
- Fund conservation easements to maintain working forests, farms, ranches, and the diverse conservation and habitat benefits they provide.
- For acres in exiting federal USDA NRCS conservation programs, enroll those acres into a new Oregon direct payment program to maintain sequestered carbon and climate benefits after NRCS enrollments expire.
- Ecologically based forest restoration and watershed improvements to reduce wildfire risk to communities and carbon emissions across ownerships.
- Natural and built water storage and delivery mechanisms (piping and improved irrigation), to respond to shifting precipitation patterns and impacts to ecosystems and agriculture.

Distribution of Revenue

Auction program revenues could be invested in natural and working lands in one or a combination of ways:

Option 1: Investment of program revenue could adhere to the existing committee and grant structure as detailed in SB 1070. In this case, eligible projects would submit a grant request to the Climate Investment Fund or Just Transition Fund for review by the appropriate committee. Funds would be awarded based on competitive project selection.

Option 2: Program revenue could be directly appropriated to corresponding state natural resource agencies for new projects or investment in existing agency programs that accomplish the intent of the legislation. This would be similar to the structure of the California Greenhouse Gas Reduction Fund. The benefit of this approach is better utilization of existing agency programs and staff capacity to achieve direct and ancillary carbon and climate related benefits. It could also reduce program implementation costs, achieve efficiencies in administration, capture existing technical assistance capacity in project development and implementation, help facilitate leverage with federal resources, and establish greater agency alignment to achieve comprehensive state climate goals.

Integration and monitoring: Regardless of the revenue distribution mechanism, it is recommended that during rulemaking, existing program statutes be reviewed for amendment to improve their integration with Oregon carbon and climate policy, and ensure appropriate use of carbon pricing program revenues. Expenditure of carbon pricing revenue should be guided by transparent criteria and consistent processes for prioritizing emission reduction projects and practices; delineating payment amounts, timing, and mechanisms; as well as monitoring and quantifying the impacts of funded projects.

Policy Recommendations

To unlock the full potential of Oregon's natural and working lands in carbon pricing legislation, **we recommend that no less than 15% and up to 25% of program revenues should be set aside after other constitutionally and statutorily mandated allocations are satisfied.** If permissible, an allocation of transportation funds to facilitate adaptation and fish passage would also accomplish natural resource goals. These funds would be designated to assist rural communities, Tribes, and small landowners in natural resource dependent geographies. Practices would harness these unique assets to address carbon sequestration, climate adaptation, and climate friendly market-based innovation that maintains working lands, diversifies revenue streams, and sustains ecosystem services.

A dedicated revenue set aside is particularly important in the case of natural and working lands, as priorities for investment include management practices that maintain and increase carbon sequestration. To accomplish long-term benefit and project scale, multiple year projects and landowner agreements are likely needed. Without a dedicated funding source, there will not be sufficient certainty to enter into contractual arrangements.

Appendix A details specific statutory amendments to SB 1070 to include references to natural and working lands and other suggested changes pertaining to program governance. We recommend consideration of these proposed changes in addition to the options and policy proposals described above.

APPENDIX A: Proposed Edits/Specific Questions relative to SB 1070:

Preamble Section:

Page 2, line 16, Insert the following –
"Whereas, greenhouse gas reductions from emissions sources and sinks can help address climate change and its impacts to human communities and ecosystems; and

Whereas, the state has a vested interest in protecting human communities, Oregon's economy and natural and working lands from the unavoidable impacts of climate change and ocean acidification; and"

Rationale: Clarifies that atmospheric greenhouse gases can be reduced through increased sequestration as well as avoided emissions;

Section 1: Greenhouse Gas Definitions:

Page 3, Line 21 – Add the following definitions:
"Greenhouse gas reduction" includes the removal of carbon dioxide from the atmosphere through carbon sequestration as well as reduced or avoided emissions of greenhouse gases. (source: California AB 1608)
"Working lands" means lands used for farming, grazing, or the production of forest products.
"Natural lands" means lands consisting of forests, grasslands, deserts, freshwater and riparian systems, wetlands, coastal and estuarine areas, watersheds, wildlands, or wildlife habitat, or lands used for recreational purposes such as parks, urban and community forests, trails, greenbelts, and other similar open-space land. For purposes of this paragraph, "parks" includes, but is not limited to, areas that provide public green space.

Rationale: Provides additional language to further clarify that atmospheric greenhouse gases can be reduced through sequestration as well as avoided emissions; provides definitions of natural lands and working lands consistent with California laws.

Greenhouse Gas Cap and Investment Program
Section 6: Statement of Purpose:

Page 4, Lines 1-3 – Modify to read: "and to promote adaptation and resilience of this state's **natural and working lands**, communities and economy in the face of climate change **and ocean acidification**."

Rationale: Strengthens the purpose statement, to include adaptation of natural and working lands in addition to communities and our economy and recognizes that increased greenhouse gases in the atmosphere result in both climate change and ocean acidification. The bill's purpose should be to promote adaptation to all three critical elements and both impacts.

Sections 7 and 8: Rules Adoption and Implementation Oversight

Page 4, (1) – The Environmental Quality Commission should be directed to do additional research to inform rulemaking. In addition to the leakage study Section 10 (2), an analysis of the differential impacts to rural and low-income Oregonians should be done to guide rulemaking.

Page 4, Line 15-17 – Include **<u>the Department of Forestry and the Department of Agriculture</u>** to the list of agencies to be consulted by the Environmental Quality Commission in developing rules

Page 4, Line 44, Add (H) – **<u>One member who represents a land conservation organization</u>**

<u>Rationale</u>: Inclusion of these agencies and organizations can provide important input to rulemaking and program oversight relative to impacts to and the role of natural and working lands and the design of any new offset protocols.

Carbon Pollution Market
Section 10:

Page 8, Line 31 – Modify (D) to read, "…to covered entities ~~*that include, but are not limited to covered entities*~~ that are part of an emission-intensive, trade-exposed industry;

<u>Rationale</u>: Targets allowances to the entities most exposed to leakage.

Page 8, Line 36 – Strike ~~*three*~~ and replace with **<u>multi-</u>**.

<u>Rationale</u>: Adds flexibility in the legislation to allow the state to set/modify rules as needed through time.

Page 9,

Line 16 Insert **<u>and</u>** immediately after the semicolon (";"):
Line 18 (ii) – Strike out the semicolon (";") and insert in its place the following: **<u>"any other greenhouse gas emissions reduction that otherwise would occur."</u>**
Lines 19 and 20 (iii) – Delete.

<u>Rationale</u>: The proposed changes to the language on additionality is intended to better align SB 1070 with the language of California's AB 32 and of the other jurisdictions in the Western Climate Initiative.

Section 14:

Page 12, Line 21 - 24 – We support prioritizing investment of auction proceeds in impacted communities as defined in Section 9 (12). However, we would like a better understanding of the geographic extent of the impacted communities to help evaluate whether the proposed percentages make sense. Further, it might make sense to state that spending funds in impacted communities is a priority of the program in the bill and establish percentages during rulemaking to avoid unintended consequences and allow for efficient adaptive management.

Rationale: This change would facilitate adaptive management of the program to achieve the best outcomes for Oregon.

Page 12, Line 35 & 36 – Modify 4 (c) to read

To the maximum extent feasible and practical give funding preferences to projects that will result in

(A) the greatest greenhouse gas emission reductions**; and**

(B) **co-benefits including but not limited to reducing risks resulting from climate change and ocean acidification and improving the resilience of natural and working lands.**

Rationale: Better reflects the dual purpose of the legislation as stated.

Section 16:

Page 13, Line 29 – 33 – As stated in comments above, we support prioritizing investment of auction proceeds in impacted communities as defined in Section 9 (12). However, we would like a better understanding of the geographic extent of the impacted communities to help evaluate whether the proposed percentages make sense. Further, it might make more sense to state that spending funds in impacted communities is a priority of the program in the bill and establish percentages during rulemaking to avoid unintended consequences and allow for efficient adaptive management.

Rationale: This change would facilitate adaptive management of the program to achieve the best outcomes for Oregon.

Page 14, Line 29 – Modify (1) by adding the following statement to the end of second sentence

"including, but may not be limited to, renewable energy, carbon sequestration in natural and working lands, weatherization, energy efficiency, climate resilience and water conservation."

Rationale: Ties the Oregon Climate Investment Fund to the purposes of the legislation and clarifies the kinds of projects that would achieve the purposes.

Page 14, Line 20 – Insert a new:
(3)(d)(I): "Natural resources and carbon sequestration."
Rationale: Adds an important area of expertise to the grant committee.
Page 14, Line 39 – Insert a new (5)(h): "Enhance the resilience of natural and working lands"

Rationale: Adds an important outcome/criterion to the grant evaluation program.

Section 20:

Page 16, Line 39 – Insert a new:
(2)(g): "Natural resources management."
Rationale: Adds an important area of expertise to the grant committee and ties the Just Transition Fund to the purposes of the legislation.

Section 25:

Page 20, Lines 28 & 30 – Correct from ~~*(3) to (4)*~~ to **(5) and (6)**

APPENDIX B: Overview of Climate Change Projected Impacts on Natural and Working lands and the Contribution of Working Lands to Oregon's Carbon Balance.

The climate of the Pacific Northwest is expected to become warmer, particularly in the summer, with little change in total annual precipitation. The seasonal distribution of precipitation is expected to shift, resulting in drier summers and wetter fall and winter periods. Overall variability in precipitation and temperature is expected to increase but with fewer cold temperature extremes.

A general increase in water stress due to warmer conditions, with no net increase in precipitation, is expected to be offset somewhat by enhanced productivity due to increasing atmospheric CO_2 concentrations. However, forest and agricultural systems are expected to become increasingly water-limited with droughts occurring over larger areas and becoming more severe. The fertilization effects of CO_2 are only available in the presence of sufficient soil moisture. Water stress in forests can lead to reduced growth rates, increased mortality from insects and disease, and increased wildfire risk. Climate change is expected to double the average annual burned area throughout the Northwest, as well as increase average fire intensity. Increasing fire frequency and severity, in combination with increased temperatures, are expected to affect profound shifts in the geographic extent of certain ecosystems.[1] Increased mortality is some areas may increase harvest pressures in others to maintain log supplies, potentially decreasing terrestrial carbon stores.

Seasonal changes in precipitation and temperature may have as much effect on working lands systems as mean shifts in regional temperature and increased weather variability.[2] In Oregon, most of the state has warmed by about two degrees (F) over the past century. Snowpack is melting earlier in the year, and the flow of meltwater into streams during summer is declining. In the coming decades, coastal waters are expected to become more acidic, streams will be warmer, wildfires may be more common, and some rangelands may convert to desert.[3]

Forest Carbon Balance

Climate change related impacts also affect the state working lands' ability to sequester carbon and mitigate further climate change. According to the Oregon Global Warming Commission's Forestry Task Force, the state's forest net gain 30 million metric tons of CO2e per year, which is equal to roughly 50% of the state's annual emissions. Despite this sizable contribution, studies indicate that; overall, Oregon's forests may be as much as 50% below their ecological carbon storage potential.[4] For instance, carbon stocking on private non-industrial forests in the Coast Range of Oregon average 107 metric tons of CO_2 equivalent per acre in above ground biomass.[5] These forests are on average between 20-59 years old. On public lands, where forest stands

[1] EPA 2016. What Climate Change Means for Oregon. Retrieved from: https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-or.pdf

[2] Creighton, J., M.Strobel, S. Hardegree, R. Steele, B. Van Horne, B. Gravenmier, W. Owen, D. Peterson, L. Hoang, N. Little, J. Bochicchio, W. Hall, M. Cole, S. Hestvik, J. Olson, 2015: Northwest Regional Climate Hub Assessment of Climate Change Vulnerability and Adaptation and Mitigation Strategies, A. Perry, Ed., United States Department of Agriculture, 52 pp.

[3] EPA 2016. What Climate Change Means for Oregon. Retrieved from: https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-or.pdf

[4] Smithwick, E. A. H. (2001). *Potential carbon storage at the landscape scale in the Pacific Northwest, USA* (Doctoral dissertation).

[5] USDA Forest Inventory and Analysis Program/OR Global Warming Commission Forestry Taskforce.

average between 60 and 199 years, the average is 278 mtCO2e.[6] Much of this unrealized potential could be achieved through improved forest management practices and extending harvest rotation.

Agriculture Carbon Balance

Agricultural activities account for around 8% of the state's emissions at roughly 5 million metric tons of CO_2e per year.[7] In contrast to other sectors, most agricultural greenhouse gas emissions are from methane and nitrous oxide rather than carbon dioxide. Slightly more than 2 million $MTCO_2$e is from methane that results from enteric fermentation (i.e. digestion of feed from livestock). About 2 million $MTCO_2$e is from nitrous oxide, estimated from nitrogen-based fertilizers used for soil management. The Agriculture Technical Committee of the Oregon Global Warming Commission (OGWC) recommended four priority strategies to reduce agricultural emissions and increasing carbon storage in the sector: 1) Increase Nutrient Use Efficiency 2) Increase Carbon Sequestration in Crop Management 3) Develop Manure to Energy Methods 4) Proactively Prepare for and Adapt to Climate Change Impacts on Water Supply.

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[6] Pinchot Institute analysis of USFS FIA Carbon Storage Data

[7] Oregon Greenhouse Gas Emissions and Recent Climate Change Developments. Bill Drumheller Interagency Sustainability Coordinators Network (ISCN) January 8th, 2014. Retrieved 8/10/17 from: http://www.oregon.gov/das/Financial/CapFin/Documents/Drumheller%20climate%20change.pdf

A Meta-Strategy for Atmospheric Recovery (Wood, University of Oregon, Environmental & Natural Resource Law Center)

11/10/17

A META-STRATEGY FOR ATMOSPHERIC RECOVERY:

FILING SUIT AGAINST THE CARBON MAJORS, FORCING THE MANAGED DECLINE OF FOSSIL FUELS, AND FUNDING CLIMATE RESTORATION THROUGH SOIL-BASED CARBON SEQUESTRATION

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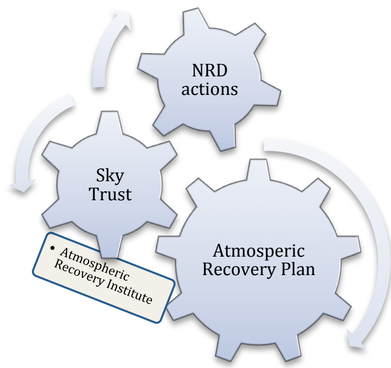
11/10/17

"In this planetary climate emergency, the level of our ambition must match the scale of the threat."

Beyond Decarbonization

Stabilizing our climate requires a full transition off of carbon intensive fossil fuels by midcentury. But as ambitious as that is, decarbonization alone is not sufficient. The global mean temperature rise of almost one degree Centigrade is a result of excess carbon emissions already flooding the atmosphere, due to roughly 150 years of industrial-scale greenhouse gas emissions.

In 2010, NASA's Dr. James Hansen, then the chief U.S. climate scientist, convened an international team of scientists to formulate a prescription to restore planetary stability. The global climate prescription has two parts: 1) rapid reduction of greenhouse gas emissions; and 2) removal of 100 Gigatons of carbon from the atmosphere through ecologically sound projects around the globe that harness the soil's ability to sequester carbon.[1] Despite the clear implications of runaway planetary heating, there is currently no entity working to aggregate the science of drawdown, develop a strategy to sustainably sequester carbon, and fund a global effort to restore the atmosphere.



This summary describes a meta-strategy for Atmospheric Recovery, consisting of three interlocking programs: 1) an Atmospheric Recovery Institute that convenes experts and initially devises an Atmospheric Recovery Plan; 2) a Natural Resource Damage (NRD) Litigation Strategy pursued by sovereign co-trustees (states, tribes, foreign nations) against the fossil fuel industry to fund the Atmospheric Recovery Plan; and 3) an Atmospheric Recovery Trust Fund (or "Sky Trust), which is a financial and administrative institution designed to receive NRD awards from U.S. courts, and to administer such funds to eligible projects (first domestically, then worldwide) that meet the parameters established in the Plan. The Fund would also monitor and administratively supervise completion of sequestration projects, and seek third-party verification of drawdown from the Atmospheric Recovery Institute.

Creating an Operable Blueprint for Drawdown: The Atmospheric Recovery Institute

Leading research points to five categories of soil-based sequestration projects: 1) reforestation; 2) regenerative (non-chemical) agricultural processes; 3) mangrove and wetlands restoration; 4) regenerative grazing practices; and 5) food forest enhancements in the tropics. Deploying these projects at scale would engage farmers, foresters, ranchers, and native peoples, and would also boost adaptation efforts by harnessing nature's own capacity to produce food, mitigate floods, and filter water. Techniques such as enhanced weathering, and more highly technological means of CO_2 extraction from the air, are still largely theoretical and in the development stage, and are potentially more costly, and less beneficial. These projects

[1] *See* Hansen, *et. al.,* 2010, *Assessing "Dangerous Climate Change:" Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature*, Plos One, http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0081648. More recently, Dr. Hansen and a team of scientists noted that a lag in the rate of emissions reduction would cause a corresponding increase in the amount of drawdown required to avert planetary catastrophe. The amount exceeds the capability of natural drawdown and would have to incorporate future technology. See Hansen, et al. 2017: Young people's burden: requirement of negative CO2 emissions. *Earth Syst. Dynam*., **8**, 577-616, doi:10.5194/esd-8-577-2017.

could conceivably be incorporated as they develop, if they meet the standards and protocols established for the Trust.

A planning institute or entity, envisioned as the Atmospheric Recovery Institute (ARI), is needed to develop, publish, assess, and update an Atmospheric Recovery Plan—setting forth a global strategy of atmospheric CO_2 drawdown with criteria to guide priority funding of projects. The plan essentially sets forth a cleanup strategy for the atmosphere, with a function similar to cleanup plans for oil spills, such as the notorious BP spill in the Gulf of Mexico. Over the long term, the ARI must have the institutional capacity and longevity to: 1) serve as a third-party monitor verifying the carbon removal achieved by the drawdown projects; 2) monitor terrestrial processes and conduct a macro carbon accounting on the global scale to verify predicted drawdown; and 3) modify the Atmospheric Recovery Plan according to adaptive management principles, taking into account opportunities from emerging methods and technology. Perhaps ideally situated in a top-flight research university, the ARI must be independent, transparent, have unimpeachable integrity, and be nimbly positioned to detect and rapidly incorporate the dynamic forces of natural change in the overall atmospheric recovery effort.

Winding Down Fossil Fuels & Funding Drawdown: Natural Resource Damage Litigation

A coordinated series of actions in state, federal, and foreign domestic courts must aim to recover sufficient Natural Resource Damages to fully fund the Atmospheric Recovery Plan. A major study by Richard Heede *et. al* traces most of the historic carbon dioxide emissions to the fossil fuels produced by about 90 fossil fuel entities.[2] Such "carbon majors," in theory, are liable for the lion's share of legacy carbon in the atmosphere. The same logic used by government to hold fossil fuel corporations liable for cleaning up oil from a marine spill positions these carbon majors to bear liability for damage to our atmosphere. Monetary damages from court judgments will fund the Atmospheric Recovery Plan to spur climate recovery using soil based sequestration projects.

In 2015, M. Wood, with D. Galpern, developed a litigation strategy known as Atmospheric Recovery Litigation (ARL) to hold carbon majors liable for funding such natural drawdown.[3] Launched by sovereign co-trustees of the atmosphere against carbon majors, the envisioned litigation is notably distinct from recent cases filed by local governments against fossil fuel companies in California seeking damages to compensate for climate harm (sea level rise, infrastructure damage, beach erosion, and the like). Those damages, aimed solely towards financing public infrastructure, will not do anything to recover climate balance, without which the catastrophes will worsen and become more frequent.

The public trust principle provides a foundation for holding the major fossil fuel corporations liable for funding atmospheric recovery. Public trust law traditionally holds polluters liable for Natural Resource Damages to public trust assets (as it does in the familiar context of oil spills). Sovereign governments, as trustees of public trust assets, are obligated to seek recovery of such Natural Resource Damages and apply them towards restoration of the resource. While ecosystem recovery on a global scale is unprecedented, the underlying legal principles and approach bear striking similarity to those traditionally applied to discrete

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[2] Richard Heede, CARBON MAJORS: ACCOUNTING FOR CARBON AND METHANE EMISSIONS 1854-2010 METHODS AND RESULTS REPORT 8–9, 25–30 (2014), http://www.climateaccountability.org/pdf/MRR%209.1%20Apr14R.pdf.

[3] Wood M.C. and D. Galpern, 2015: *Atmospheric Recovery Litigation: Making the Fossil Fuel Industry Pay to Restore a Viable Climate System*, Environ. Law, 45(2), 259-337, ISSN 0046-2276, draft available at: https://law.uoregon.edu/images/uploads/entries/atmospheric-recovery-litigation--making-the-fossil.pdf. The strategy was originated by M. Wood and then discussed in NATURE'S TRUST: ENVIRONMENTAL LAW FOR A NEW ECOLOGICAL AGE 184-85 (Cambridge University Press 2013).

resources. Just as an oil company must pay for cleanup of an oil spill in marine waters, so are the carbon majors situated to pay for atmospheric cleanup through Natural Resource Damages.

Atmospheric Trust Litigation (cases spearheaded by Our Children's Trust) has established some bedrock principles for atmospheric natural resource damage actions.[4] In *Juliana v. United States*, a landmark suit brought by youth against the federal government, in which the fossil fuel industry intervened, the U.S. District Court of Oregon announced a constitutional right under the federal public trust doctrine, and the due process clause, to a "stable climate system capable of supporting human life." Similarly, a Washington state case brought by youth, *Foster v. Department of Ecology*, explicitly found an atmospheric trust, holding that the public trust principle constitutionally obliged government to restore a healthy climate system. These decisions, while brought by youth beneficiaries of the trust against their government, and not seeking damages to the atmosphere (but rather decarbonization), nevertheless establish a framework in which the government trustees are constitutionally responsible for restoring climate balance.

In Atmospheric Recovery Litigation claiming Natural Resource Damages, sovereign co-trustees – states (or county subdivisions), tribes, and foreign nations – would seek a remedy asking for disgorgement of profits and assets retained by the fossil fuel industry. Monetary awards received by the plaintiff sovereign trustees will be deposited in the Atmospheric Recovery Trust Fund (or Sky Trust) described below. The Atmospheric Recovery Litigation Campaign may be launched in coordinated fashion to support Phase I domestic U.S. projects, and in Phase II, projects in other countries. Judgments from cases brought in other countries may be domesticated (enforced) in U.S. courts, with the money deposited in the Sky Trust, to support drawdown projects in those nations or elsewhere.

Disbursing Damages to Drawdown Projects: The Atmospheric Recovery Trust Fund

A separate and independent financing entity, the Atmospheric Recovery Trust Fund (or Sky Trust), must be created or emerge from an existing institution to financially administer the Recovery plan. This trust, much like the Environmental Mitigation Trust established in the Volkswagen litigation settlement, would be a court-ordered Trust dedicated to remedying the harm from fossil fuel pollution. The Trust will carry out two corresponding roles: 1) receive and fiscally manage Natural Resource Damage monetary awards from court judgments, dispersing such money into qualifying drawdown projects; and 2) administratively implement the projects to carry out the Atmospheric Recovery Plan.

The Trust will solicit project proposals from states, tribes, cities, counties, and corporate or nonprofit entities, selecting projects that meet the criteria established in the Atmospheric Recovery Plan. The Trust will enter into contractual relationships with these proponents to carry out their projects using local partners and independent experts where necessary, and monitor the projects – all of which must ensure accountability, additionality, effectiveness, and permanency. In Phase I, the Trust will accept only domestic projects within the United States, but in Phase II will be positioned to accept projects from other nations, building on the structure created. While the Trust will be a domestic U.S. entity, its board could have representation from select global entities such as the United Nations Environment Programme, the IPCC, or the Green Climate Fund.

"It is not enough that we do our best; sometimes we must do what is required." Winston Churchill

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[4] Atmospheric Trust Litigation (ATL) and Atmospheric Recovery Litigation (ARL) are distinct legal campaigns, with different plaintiff groups and defendant groups, and different kinds of remedies, but both rely fundamentally on the public trust framework to provide legal redress towards recovering the climate system. ATL is brought by youth plaintiffs, as beneficiaries of the atmospheric trust, against government trustees to gain injunctions requiring enforceable, science-based climate recovery plans. The campaign is largely directed towards energy transition and de-carbonization before irrevocable climate thresholds are passed. Atmospheric Recovery Litigation (ARL) is brought by government trustees against polluter fossil fuel industries (carbon majors) seeking natural resource damages to fund an Atmospheric Recovery Plan.

Summer Streamflow Deficits from Regenerating Douglas-fir Forests in the Pacific Northwest (Perry and Jones)

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SPECIAL ISSUE PAPER

Summer streamflow deficits from regenerating Douglas-fir forest in the Pacific Northwest, USA

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Abstract

Despite controversy about effects of plantation forestry on streamflow, streamflow response to forest plantations over multiple decades is not well understood. Analysis of 60-year records of daily streamflow from eight paired-basin experiments in the Pacific Northwest of the United States (Oregon) revealed that the conversion of old-growth forest to Douglas-fir plantations had a major effect on summer streamflow. Average daily streamflow in summer (July through September) in basins with 34- to 43-year-old plantations of Douglas-fir was 50% lower than streamflow from reference basins with 150- to 500-year-old forests dominated by Douglas-fir, western hemlock, and other conifers. Study plantations are comparable in terms of age class, treatments, and growth rates to managed forests in the region. Young Douglas-fir trees, which have higher sapwood area, higher sapflow per unit of sapwood area, higher concentration of leaf area in the upper canopy, and less ability to limit transpiration, appear to have higher rates of evapotranspiration than old trees of conifer species, especially during dry summers. Reduced summer streamflow in headwater basins with forest plantations may limit aquatic habitat and exacerbate stream warming, and it may also alter water yield and timing in much larger basins. Legacies of past forest management or extensive natural disturbances may be confounded with effects of climate change on streamflow in large river basins. Continued research is needed using long-term paired-basin studies and process studies to determine the effects of forest management on streamflow deficits in a variety of forest types and forest management systems.

KEYWORDS

climate change, native forests, plantations, stationarity, succession, water scarcity

1 | INTRODUCTION

Widespread evidence that streamflow is declining in major rivers in the United States and globally has raised concerns about water scarcity (Adam, Hamlet, & Lettenmaier, 2009; Dai, Qian, Trenberth, & Milliman, 2009; Luce & Holden, 2009; Vörösmarty, Green, Salisbury, & Lammers, 2000). Climate change and variability are implicated as causes of many streamflow trends (Lins & Slack, 1999, 2005; McCabe & Wolock, 2002; Mote et al., 2003; Hodgkins, Dudley, & Huntington, 2003, 2005; Stewart, Cayan, & Dettinger, 2004, 2005; Nolin & Daly, 2006; Hamlet & Lettenmaier, 2007; Barnett et al., 2008; Jefferson, Nolin, Lewis, & Tague, 2008; Lara, Villalba, & Urrutia, 2008; Dai et al., 2009; Kennedy, Garen, & Koch, 2009; Jones, 2011). However, large-scale plantation forestry, often using non-native tree species, is expanding in much of the temperate zone on Earth, despite widespread evidence that intensive forestry reduces water yield (Cornish & Vertessy, 2001; Andréassian, 2004; Brown, Zhang, McMahon, Western, & Vertessy, 2005, Farley, Jobbágy, & Jackson, 2005; Sun et al., 2006; Little, Lara, McPhee, & Urrutia, 2009). Water yield reductions are greater in older plantations, during dry seasons, and in arid regions (Andréassian, 2004; Brown et al., 2005; Farley et al., 2005; Sun et al., 2006). Yet, downstream effects of forestry are debated (van Dijk & Keenan, 2007).

Despite general studies of water partitioning in forested basins (e.g., Budyko, 1974, Zhang, Dawes, & Walker, 2001, Jones et al., 2012), it is unclear how streamflow varies during forest succession, relative to tree species, age, or growth rates in native forest and forest plantations (Creed et al., 2014). In the Pacific Northwest of the United States, forest plantations have reduced summer streamflow relative to mature and old-growth forest (Hicks, Beschta, & Harr, 1991; Jones & Post, 2004). However, the magnitude, duration, causes, and consequences of summer water deficits associated with forest plantations are not well understood.

In the Pacific Northwest, large areas of old-growth forest have been converted to forest plantations. We examined how changes in forest structure and composition have affected streamflow using multiple paired-basin experiments in western and southwestern Oregon, where regenerating forests are currently aged 40 to 50 years, and reference forests are aged 150 to 500 years. Many studies have reported on these experiments, including vegetation ecology (e.g., Marshall & Waring, 1984; Halpern, 1989; Halpern & Franklin, 1990; Halpern & Spies, 1995; Lutz & Halpern, 2006; Halpern & Lutz, 2013) and hydrology (e.g., Rothacher, 1970; Harr, Fredriksen, & Rothacher, 1979; Harr & McCorison, 1979; Harr, Levno, & Mersereau, 1982; Hicks et al., 1991; Jones & Grant, 1996, Jones, 2000; Jones & Post, 2004, Perkins & Jones, 2008; Jones & Perkins, 2010; Jennings & Jones, 2015). We asked:

1. How has daily streamflow changed over the past half-century in reference basins with 150- to 500-year-old forest?

TABLE 1 Name and abbreviation, area, elevation range, natural vegetation and vegetation age when streamflow records began, streamflow gaging method and record length, harvest treatment, logging methods, and treatment dates for basins used in this study

Basin name	Area (ha)	Elevation range (m)	Natural vegetation	Streamflow record length, instrumentation[b]	Treatment, date[a]	Logging method
Coyote 1 COY 1	69.2	750–1,065	Mixed conifer	1963–81 V; 2001–present V	Roads 1970; 50% overstory selective cut, 1971	Tractor yarded
Coyote 2 COY 2	68.4	760–1,020	Mixed conifer	1963–81 V; 2001–present V	Permanent roads 1970; 30% 2- to 3-ha patch cuts, 1971	16% high-lead cable yarded; 14% tractor yarded.
Coyote 3 COY 3	49.8	730–960	Mixed conifer	1963–81 V; 2001–present V	Permanent roads 1970; 100%; clearcut 1971	77% high-lead cable yarded; 23% tractor yarded.
Coyote 4 COY 4	48.6	730–930	Mixed conifer	1963–81 V; 2001–present V	Reference	N/A
Andrews 1 AND 1	95.9	460–990	450- to 500-year-old Douglas-fir forest	1952–present (1952–present T [rebuilt 1956]; 1999-present SV)	100% clearcut 1962–1966, broadcast burn 1966	100% skyline yarded
Andrews 2 AND 2	60.7	530–1,070	450- to 500-year-old Douglas-fir forest	1952–present (1952–present T; 1999–present SV)	Reference	N/A
Andrews 3 AND 3	101.2	490–1,070	450- to 500-year-old Douglas-fir forest	1952–2005 T; 1999–present SV	Roads 1959; 25% patch cut 1962, broadcast burn 1963	25% high-lead cable yarded
Andrews 6 AND 6	13.0	863–1,013	130- to 450-year-old Douglas-fir forest	1964–present; (1964–1997 H; 1997–present T; 1998 present SV)	Roads, 1974; 100% clearcut 1974; broadcast burn 1975	90% high-lead cable yarded; 10% tractor yarded
Andrews 7 AND 7	15.4	908–1,097	130- to 450-year-old Douglas-fir forest	1964–1987; 1995–present (1964–1997 H; 1997–present T; 1998–present SV)	Roads 1974; 60% shelterwood cut 1974; remaining overstory cut 1984; broadcast burn lower half of basin 1975; 12% basal area thin 2001	40% skyline yarded; 60% tractor yarded.
Andrews 8 AND 8	21.4	955–1,190	130- to 450-year-old Douglas-fir forest	1964–present (1964–1987 H; 1987 present T; 1973–1979 SV, 1997–present SV)	Reference	N/A
Andrews 9 AND 9	9	425–700	130- to 450-year-old Douglas-fir forest	1969–present (1969–1973 H; 1973 present T; 1973–1979 SV, 1997 present SV)	Reference	N/A
Andrews 10 AND 10	10	425–700	130- to 450-year-old Douglas-fir forest	1969–present (1969–1973 H; 1973 present T; 1973–1979 SV, 1997–present SV)	100% clear-cut 1975; no burn	100% high-lead cable yarded

Sources: Harr et al., 1979; Rothacher, 1965; Harr et al., 1982; Rothacher, Dyrness, & Fredriksen, 1967; Jones & Post, 2004.

[a]Broadcast burns were controlled burns over the cut area intended to consume logging debris.

[b]H = H-flume; T = trapezoidal flume; V = V-notch weir or plate. Summer V-notch weirs (SV) have been used for improved discharge measurements over the following periods: since 1999 at Andrews 1, 2, and 3; since 1998 at Andrews 6, 7, and 8; and from 1969 to 1973 and since 1997 at Andrews 9 and 10.

2. What are the trends in daily streamflow over 40- to 50-year periods, from basins with regenerating forests compared to reference basins?
3. How are changes in summer streamflow related to forest structure and composition in mature and old-growth forests versus forest plantations?

2 | STUDY SITE

The study examined streamflow changes in eight pairs of treated/reference basins in five paired-basin studies. Five of the basin pairs (eight basins) were located in the H.J. Andrews Experimental Forest (122°15′W, 44°12′N) in the Willamette National Forest. Three basin pairs (four basins) were located at Coyote Creek in the South Umpqua Experimental Forest (122°42′W, 43°13′N) in the Umpqua National Forest (Table 1; Figure 1). Basins are identified as Andrews 1, 2, etc. = AND 1, 2, etc.; Coyote 1, 2, etc. = COY 1, 2, etc. (Table 1).

The geology of the study basins is composed of highly weathered Oligocene tuffs and breccias that are prone to mass movements. The upper elevation portion of the Andrews Forest (above ~800 m, AND 6, AND 7, AND 8) is underlain by Miocene andesitic basalt lava flows (Dyrness, 1967; Swanson & James, 1975; Swanson & Swanston, 1977). Soils are loamy, well-drained, and moderately to highly permeable, with considerable variation in depth and rock content (Rothacher, 1969; Dyrness, 1969; Dyrness & Hawk, 1972).

The Andrews Forest ranges from 430 to 1,600 m elevation; study basins range from 430 to 1,100 m elevation (Table 1). Area-averaged slope gradients are >60% at low elevation (AND 1, AND 2, AND 3, AND 9, AND 10) and 30% at high elevation (AND 6, AND 7, AND 8). Mean daily temperature ranges from 2°C (December) to 20°C (July) at 430 m and from 1°C (December) to 17°C (July) at 1300 m. Mean annual precipitation is 2300 mm, >75% of precipitation falls between November and April, and actual evapotranspiration averages 45% of precipitation. The South Umpqua Experimental Forest (Coyote Creek basins) ranges from 730 to 1065 m elevation. Most slope gradients are <40% (Arthur, 2007). Mean daily temperature (at USHCN station OR356907, 756 m elevation, 30 km SE of Coyote Creek) ranges from 3°C (December) to 20°C (July). Mean annual precipitation (at OR356907) is 1,027 mm, >80% of precipitation falls between November and April, and actual evapotranspiration averages 45% of precipitation.

Study basins are located along a gradient of seasonal snow depth and duration (Harr, 1981, 1986). At high elevation (>800 m, AND 6, AND 7, and AND 8), average snowpack water equivalent on April 30 exceeds 700 mm (30% of annual precipitation), and snow may persist for 6 months, whereas at low elevation (<700 m, AND 9, AND 10), snow rarely persists more than 1–2 weeks and usually melts within 1–2 days; peak snowpack water equivalent is ~2% of precipitation

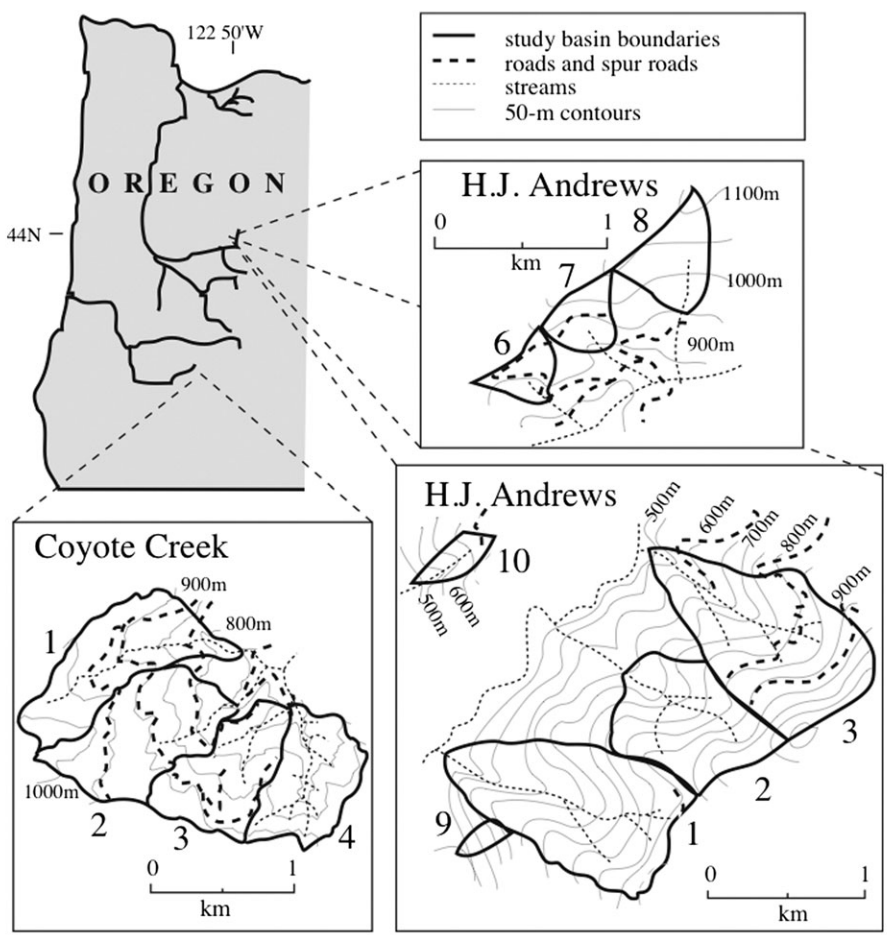

FIGURE 1 Location of study basins in western Oregon

(Harr et al., 1979; Harr & McCorison, 1979; Harr et al., 1982; Perkins & Jones, 2008). Snow at the South Umpqua Experimental Forest (Coyote Creek) usually melts within 1–2 weeks.

Vegetation at the Andrews Forest is Douglas-fir/western hemlock forest. Mature and old-growth forest regenerated after wildfires in the early 1500s and mid-1800s (Weisberg & Swanson, 2003, Tepley, 2010, Tepley, Swanson, & Spies, 2013). Overstory canopy cover is 70% to 80% and leaf area index is >8 (Dyrness & Hawk, 1972; Marshall & Waring, 1986; Lutz & Halpern, 2006). Vegetation at the South Umpqua Experimental Forest is mixed conifer (Douglas-fir, white fir, incense cedar, sugar pine), and overstory canopy cover is 70% to 80% (Anderson et al., 2013).

At the Andrews Forest, the first paired-basin experiment began in 1952 (AND 1, 2, 3); a second paired basin experiment began in 1963 (AND 6, 7, 8), and a third paired-basin experiment began in 1968 (AND 9, 10), with continuous records except at AND 7 (Table 1). Pre-treatment periods exceeded 7 years in all cases and were 10 years for AND 1/2, AND 6/8, and AND 7/8. Streamflow instrumentation changed in some basins over the period of record (Table 1). Because of the timing of instrumentation changes at AND 9/10, AND 2 is used as the reference basin for AND 10 (see Supporting Information). At the South Umpqua Experimental Forest, the Coyote Creek paired-basin experiment began in 1963 (Table 1). The pre-treatment period was 7 years. Despite a break in the record from 1981 to 2000, streamflow instrumentation at Coyote Creek has not changed (M. Jones, personal communication).

3 | METHODS

This study examined changes in daily average streamflow and its relationship to climate and forest structure and species composition in paired basins. Climate, vegetation, and streamflow have been measured for multiple decades at the Andrews Forest and Coyote Creek (see Supporting Information). Tree-level vegetation data were used to calculate basal area for all species, proportions of basal area for major species, and size class distributions.

Daily streamflow data for the period of record were used to calculate the change in streamflow by day of water year utilizing the method developed by Jones and Post (2004). *R*, the logarithm of the ratio of daily streamflow at the treated basin *T* and reference (control) basin *C* for year *y* and day *d* was calculated following Eberhardt and Thomas (1991) as

$$R_{y,d} = \ln\left(\frac{T_{y,d}}{C_{y,d}}\right). \tag{1}$$

The value M_{pd} was defined as the mean of *R* on day *d* for all years *y* in each period *p*.

The percent difference $\Delta_{p,d}$ between the treated: reference ratio of streamflow on day *d* in the post-treatment period *p* compared to $M_{p,d}$ in the pre-treatment period ($M_{p=0,d}$), was:

$$\Delta_{p,d} = 100\left[e^{\left(M_{p,d}-M_{0,d}\right)}-1\right] \tag{2}$$

The 15-day smoothed percent change in daily streamflow, *S*, was calculated for all days *d* in each period *p*.

The smoothed daily percent difference S_{pd} was averaged for 5-year post-treatment periods and plotted as a function of day of the water year. S_{pd} also was summed by month and plotted as a function of time (year). Percent changes in daily streamflow were calculated for eight treated/reference basin pairs: COY 1/4, COY 2/4, COY 3/4, AND 1/2, AND 3/2, AND 6/8, AND 7/8, and AND 10/2. The significance of percent changes was assessed based on comparison with the 15-day smoothed values of the pre-treatment standard error of P_{pd}.

A daily soil water balance was created for AND 2 based on mean daily values of precipitation and discharge, daily evapotranspiration estimated from S_{pd} (Jones & Post, 2004), and mean daily snow water equivalent modeled in Perkins and Jones (2008). In addition, long-term trends in streamflow were calculated for each day of the water year from the beginning of the record to 1996, for AND 2, 8, and 9, following Hatcher and Jones (2013; see Supporting Information).

Flow percentiles were calculated for each gage record, and the numbers of days of flow below each percentile were tallied by water year. The difference in numbers of days below selected percentiles between the treated and reference basin for 1995 to 2005 was calculated and compared to summer discharge at the reference basin for 100% treated/reference pairs.

4 | RESULTS

The structure and composition of native mature and old-growth forest in reference basins varied, reflecting wildfire history, but was stable over the study period. Basal area ranged from 66 to 89 m^2/ha depending on the basin and the year (Table 2). Douglas-fir (*Pseudotsuga menziesii*) was the dominant species, representing 55 to more than 90% of basal area, with varying amounts of western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*) in AND 2 and AND 8, and California incense cedar (*Calocedrus decurrens*) and white fir (*Abies concolor*) in COY 4 (Table 2). Trees in AND 2 (N-facing) and AND 8 (upper elevation) were large, with weighted mean stem diameter of roughly 0.66 m. In contrast, trees were smaller on the low elevation, SW-facing, relatively hot, dry slopes of AND 9, and the mid-elevation COY 4 in southwest Oregon, with mean diameter of just over 0.3 m (Table 2). Stem density ranged from 87 stems per hectare at the N-facing AND 2 to over 400 stems per hectare at the SW-facing AND 9. Over a 25-year period, stem density and basal area were stable in AND 2, although there was a slight net loss of Douglas-fir and a gain of western hemlock (Table 2). The size-class distributions of Douglas-fir reveal moderate-severity historical fire in AND 2 and moderate to high-severity fire AND 8 in the mid-1800s, which produced cohorts of regenerating Douglas-fir (Figure 2).

TABLE 2 Vegetation characteristics of the study basins, sampled over the period 1981 to 2011

					Basal area								Stem density (stems per hectare)	
					(m²/ha)	As %								
Watershed	*N* of plots	Plot size (m²)	Year	Age	All	PSME	TSHE	THPL	ABCO	CADE	PILA	Other[a]	All	PSME
Treated patches														
AND 1	132	250	2007	40	33 ± 14	85	3	1	0	0	0	11	1,454	919
AND 3	61	250	2007	43	35 ± 12	80	11	2	0	0	0	7	1,857	621
AND 6	22	250	2008	34	35 ± 9	77	11	9	0	0	0	3	1,107	699
AND 7	24	250	2008	24	23 ± 10	70	9	4	0	0	0	17	900	551
AND 10	36	150	2010	35	27 ± 12	81	4	2	0	0	0	13	893	437
COY 1[be]	-- [f]	-- [f]	2011	35–200[g]	66	56	5	0	17	12	5	5	992	194
COY 2[c]	4	150	2006	35	31 ± 12	82	0	0	0	13	0	5	1,733	1,150
COY 3[c]	4	150	2006	35	45 ± 13	80	0	0	0	10	0	10	1,533	1,083
Reference														
AND 2	67	250	1981	150–475[d]	69 ± 29	70	24	2	0	0	0	4	262	67
	67	250	2006	175–500[d]	72 ± 29	65	29	2	0	0	0	4	438	87
AND 8	22	1,000	2003	175–500[d]	86 ± 24	64	26	9	0	0	0	2	580	144
	22	1,000	2009	175–500[d]	89 ± 24	64	26	9	0	0	0	2	565	139
AND 9	16	1,000	2003	175–500[d]	84 ± 25	92	4	0	0	0	0	4	630	434
	16	1,000	2009	175–500[d]	85 ± 25	92	5	0	0	0	0	3	602	417
COY 2[b]	--[f]	--[f]	2011	150–350[g]	89	61	0	0	10	17	11	1	1,169	172
COY 4[b]	-- [f]	-- [f]	2011	150–350[g]	66	55	5	0	18	11	5	6	975	183

Basal area is mean ± standard deviation. PSME = *Pseudotsuga menziesii* (Douglas-fir); TSHE = *Tsuga heterophylla* (western hemlock); THPL = *Thuja plicata* (western red cedar); ABCO = *Abies concolor* (white fir); CADE = *Calocedrus decurrens* (California incense cedar); PILA = *Pinus lambertiana* (sugar pine); -- = not available.

[a]Other (at Coyote Creek) includes *Arbutus menziesii* (madrone), *Pinus ponderosa* (ponderosa pine), and *Taxus brevifolia* (Pacific yew). Other (at the Andrews Forest) includes *Acer macrophyllum* (bigleaf maple), *Castanopsis chrysophylla* (giant chinquapin), and *Prunus emarginata* (bitter cherry).

[b]Based on 2011 stand exam data for matrix (not forest plantations) from Anderson et al., 2013.

[c]Source: Arthur, 2007.

[d]Multi-age stand with mixed-severity fire history.

[e]Coyote 1 was sampled in 2006 (Arthur, 2007) and 2011 (Anderson et al., 2013).

[f]Data from a forestry stand examination, not from plots, and no standard error is provided.

[g]Source: Rothacher, 1969.

Basal area and growth rates in the 34- to 43-year-old plantations in the treated basins are at the lower end of those reported for managed plantations in the region (Figure 3). Basal area at the most recent measurement period (2007 to 2010) ranged from 27 to 35 m^2/ha, or between one third and one half of the basal area in the corresponding reference basin (Table 2). Douglas-fir, which was planted in the treated basins, was the dominant species, representing more than 80% of basal area. Stem density was 5 to 10 times higher in plantations than matched reference basins and ranged from 533 to more than 1,700 stems per hectare (Table 2). Mean diameters in plantations were one third to one fifth of those in corresponding reference basins, except for COY 1, where the large mean stem diameter (31 cm) reflects the retention of 50% of the overstory from the shelterwood harvest (Tables 1 and 2). Trees were smallest in AND 7 (shelterwood harvest, plantation aged 34 years) and largest in 100% clearcut and burned basins AND 1 (plantation, aged 40 years) and COY 4 (plantation, aged 35 years). AND 10, which was clearcut but not burned, had a high number of small stems (plantation, aged 35 years; Tables 1 and 2; Figure 2). Adjusting for age, rates of basal area growth were similar in all the 100% clearcut basins. The unburned basin (AND 10) and the shelterwood harvest basin (AND 7) had slightly lower rates of growth in the third decade after harvest (AND 10) and a precommercial thin (12% basal area removal) at year 28 in AND 7, but rates were similar by 35 years (Figure 3).

The daily soil water balance for the reference basin (AND 2, Figure 4) reveals extremely low rates of evapotranspiration and soil moisture in old-growth forests during the summer (July through September). Evapotranspiration is limited by low temperature in winter and low soil moisture in summer.

Daily streamflow has not changed in reference basins (Figure 5). Runoff declined slightly during the periods of snowmelt, but these minor changes were significant only at AND 2 (Figure 5). Summer streamflow did not change over time.

Conversion of old-growth forest to Douglas-fir plantations, which reached 34 to 43 years of age by the end of the record analyzed here,

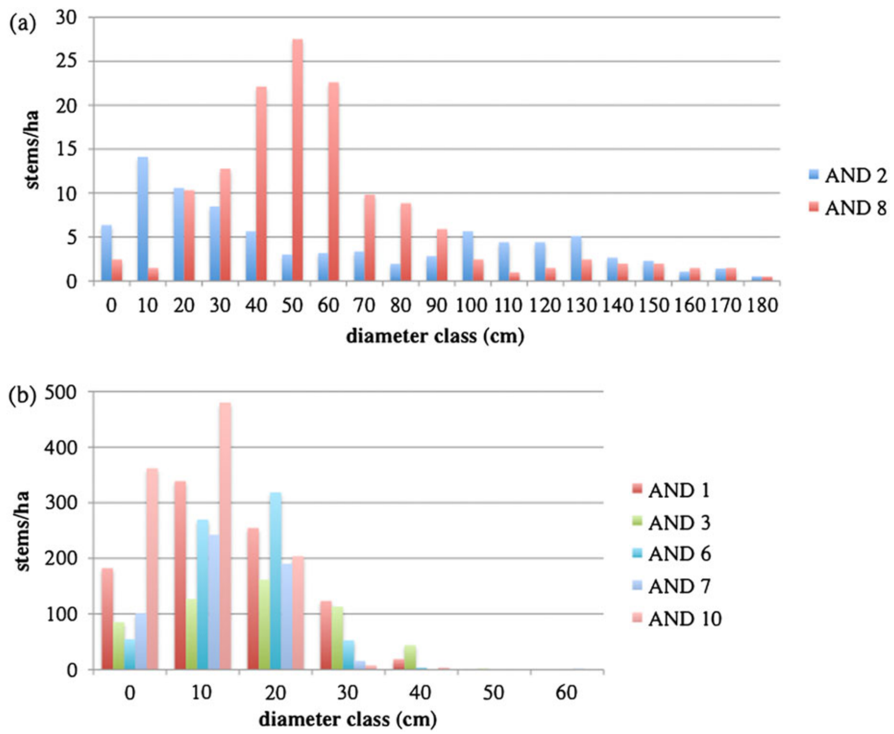

FIGURE 2 Size class distributions of Douglas-fir (*Pseudotsuga menziesii*, PSME) in plantations and reference basins in the Andrews Forest. (a) Reference basins used in this study: AND 2 (2006), AND 8 (2009). (b) Basins with young Douglas-fir plantations: AND 1 (aged 40 years, 2007), AND 3 (clearcut patches, aged 43 years, 2007), AND 6 (aged 34 years, 2008), AND 7 (aged 34 years, 2008), AND 10 (aged 35 years, 2010)

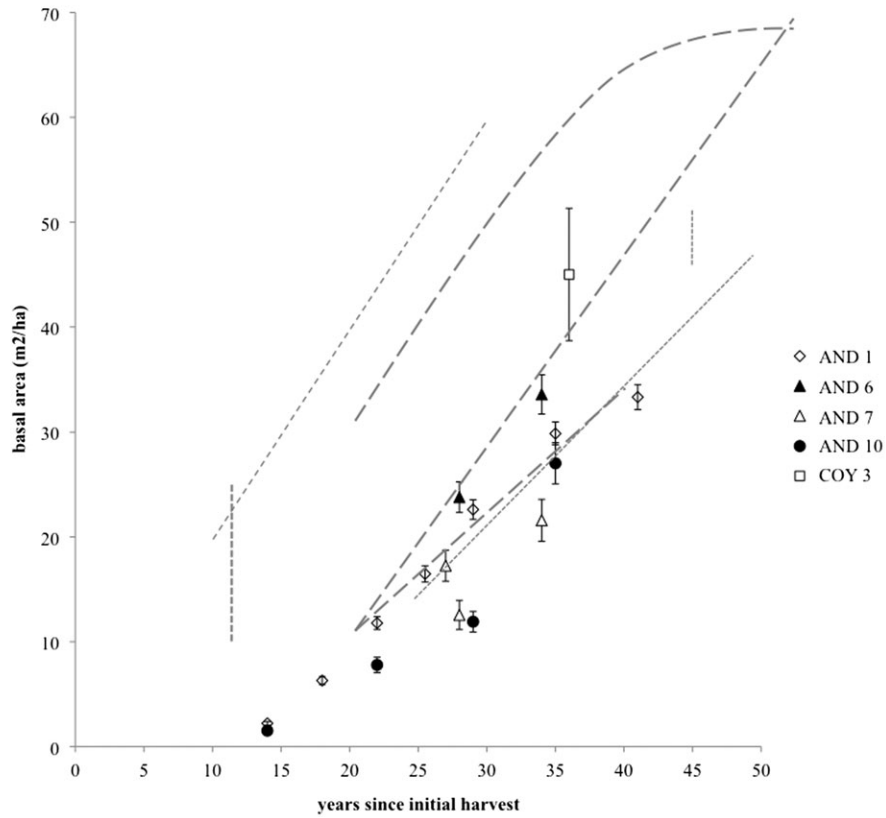

FIGURE 3 Basal area as a function of time since treatment in basins with forest plantations. Symbols are means ± standard error from numbers of plots shown in Table 2. The diagonal thick grey dashed lines are the basal area reported from control (unthinned) plots (upper line), heavily thinned plots (lower line), and lightly thinned plots (middle line) in the Hoskins levels-of-growing-stock (LOGS) installation (site II) in western Oregon (Marshall & Curtis, 2002). The diagonal thin grey dashed line indicates average annual basal area for Douglas-fir plantations on relatively high site productivity locations affected by various levels of infection from Swiss needle cast in the Oregon Coast Range (Maguire, Kanaskie, Voelker, Johnson, & Johnson, 2002). The thin grey diagonal dotted line indicates basal areas for experimental Douglas-fir plantations at low site productivity locations (site V) at Wind River (100 km north of the Andrews Forest, at a similar elevation to the experimental basins; Harrington & Reukema, 1983). The vertical grey dotted line is estimated Douglas-fir basal area from growth and yield models for 45-year-old stands (Marshall & Turnblom, 2005). The vertical grey dashed line is range of basal areas in stands of Douglas-fir, western hemlock, and mixtures (Amoroso & Turnblom, 2006)

had a major effect on summer streamflow. By the mid-1990s, average daily flow in summer (June through September) in basins with plantation forests had declined by roughly 50% relative to the reference basins with 150- to 500-year-old forests (Figure 6a). When plotted by time since harvest, summer streamflow deficits appeared when plantation forests reached 15 years of age (Figure 6b). The trend of declining summer streamflow was temporarily reversed in the late 1980s, especially at AND 1/2 and AND 6/8, after a severe freezing

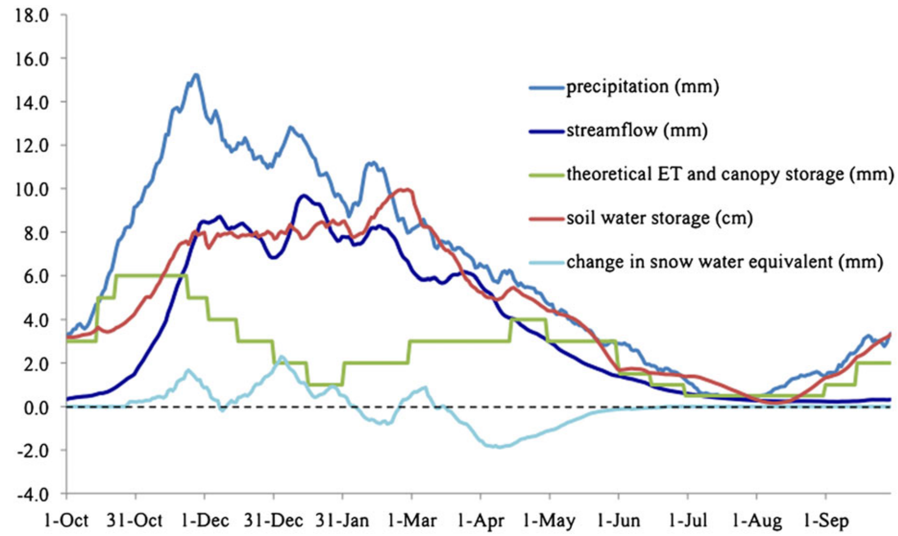

FIGURE 4 Water balance of mean daily values of precipitation (P), streamflow (Q), ET, snow water equivalent (N), and soil water storage (S) in AND 2, based on data from 1953 to 2003 water years, where S = P − Q − ET − ΔN. Daily ET was estimated from the response of AND 1/2 to clearcutting calculated by Jones and Post (2004) and from summer sapflow measured in AND 2 by Moore et al., (2004). Snow water equivalent was based on average modeled daily values from Perkins and Jones (2008)

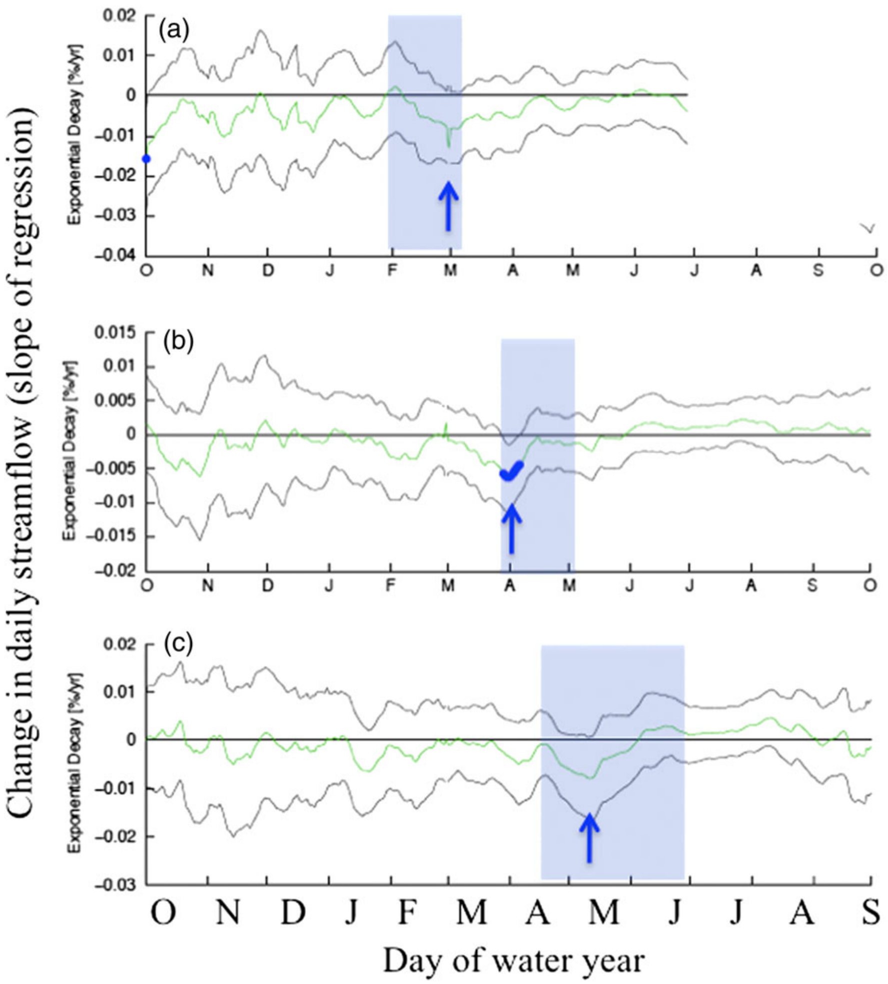

FIGURE 5 Streamflow change for period of record to 1996, by day of water year (October to September) for three reference basins: (a) AND 9 (400 to 700 m), (b) AND 2 (500 to 1,000 m), and (c) AND 8 (800 to 1,100 m). The green line is the trend in streamflow (positive or negative) on that day of the year, relative to the long-term mean streamflow on that day (indicated as zero). Black lines are the 95% confidence interval around the trend. Blue arrows indicate days of declining streamflow, and dark blue lines are days of significant declines in streamflow; declines are significant only at AND 2. Shaded boxes show the period of snowmelt from Perkins and Jones (2008). K. Moore, unpublished data

event in November of 1986. A pre-commercial thin (12% basal area) in AND 7 in 2001 did not slow the decline of summer streamflow.

When examined by day of year, forest harvest produced large streamflow increases from June through December in the first 10 years after harvest (Figure 7). Initial summer streamflow surpluses were lowest, and disappeared most quickly, in 50% thinned ("shelterwood") basins (AND 7, COY 1), and they were highest at the 100% clearcut basins (AND 1, 6, 10, COY 3; Figure 7). Conversion of mature and old forest to young plantations produced streamflow surpluses in winter and spring of 25% to 50%, which persisted virtually unchanged to the present in the Andrews Forest, but not at the drier, more southerly Coyote Creek (Figure 7).

By 20 to 25 years after 100% clearcutting, summer streamflow was lower in all plantation forests compared to reference basins

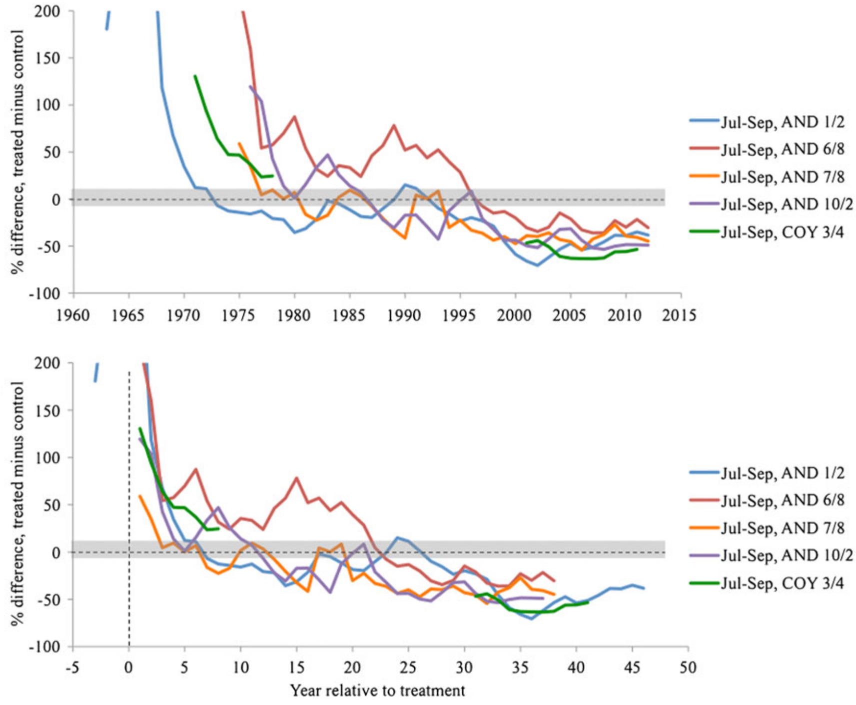

FIGURE 6 Trends in average daily streamflow (July through September) in basins with forest plantations as a percent of streamflow in the reference basin, for five basin pairs with 100% clearcut basins. (a) by year and (b) by time since treatment. Basin pair names include treated/reference. Percents are 3-year running means. Grey box is the mean ± the standard error of the treated-reference basin relationship from July to September during the pre-treatment period. Vertical axis maximum omits years when summer streamflow (July through September) at the treated basin exceeded 200% of pre-treatment level. Maximum percent increases (in unsmoothed data) were 683% at AND 1 (in 1966, fourth year of 1962-1966 clearcutting treatment); 328% at AND 6 (in 1975, one year after treatment); 90% at AND 7 (in 1974, year of treatment); 203% at AND 10 (in 1976, one year after treatment); and 149% at COY 3 (in 1971, year of treatment). Blue detached line shows initial increase when clearcutting (1962 to 1966) began in AND 1. Blue line shows apparent "hydrologic recovery" at AND 1 circa 1990 noted by Hicks et al. (1991); while red line shows increasing streamflow after 1986; both trends are attributable to an extreme freezing event that killed regenerating vegetation. Overall pattern shows no hydrologic recovery to pre-treatment conditions

(Figure 7a–e) and also in one 25% patch cut basin (Figure 7g). In 100% clearcut basins, summer streamflow deficits began by early July, and persisted until early October (AND 1, AND 7, Figure 7a,c), to the end of November (AND 6, AND 10, Figure 7b,d), or to the end of December (COY 3, Figure 7e). Deficits were largest in August and September, when streamflow from forest plantations was 50% lower than from reference basins. Summer deficits did not emerge over time in treatments involving shelterwood (50% thinned, COY 1) and very small openings (0.6- to 1.3-ha patch cuts, COY 2; Figure 7f,h). Relative to 50% thinning (shelterwood) and very small openings, intermediate-sized openings (8-ha patch cuts, AND 3) produced larger initial summer surpluses and persistent summer deficits. The largest openings (20- to 100-ha clearcuts) produced the largest summer surpluses and the largest, persistent summer deficits, which extended into the fall season (Figure 7a–d). Thinning of young forest (AND 7) did not counteract summer streamflow deficits.

Summer streamflow deficits occurred during the period of minimum flow, when soil moisture is most limiting (Figures 4 and 7). The duration of summer streamflow deficits (defined as the difference in the number of days below the first percentile in basins with plantations vs. reference basins) was greater during dry compared to wet summers, at low compared to high elevation, and at the more southerly Coyote Creek compared to the Andrews Forest (Figure 8). Forest plantations that were aged 25 to 35 years in 1995 to 2005 had as many as 100 more days with flow below the first percentile compared to the reference basin (Figure 8). Within a basin pair, the number of days of flow below the first percentile increased in dry relative to wet summers (Figure 8).

5 | DISCUSSION

This study showed that, relative to mature and old-growth forest dominated by Douglas-fir and western hemlock or mixed conifers, forest plantations of native Douglas-fir produced summer streamflow deficits within 15 years of plantation establishment, and these deficits have persisted and intensified in 50-year-old forest stands. Forest stands in the study basins, which are on public forest land, are representative of managed (including thinned) forest stands on private land in the region, in terms of basal area over time (Figure 3), age (10 to 50 years), clearcut size (20 ha), and average rotation age (50 years) (Lutz & Halpern, 2006; Briggs, 2007). There are no significant trends in annual or summer precipitation (Abatzoglou, Rupp, & Mote, 2014) or streamflow at reference basins over the study period. This finding has profound implications for understanding of the effects of land cover change, climate change, and forest management on water yield and timing in forest landscapes.

The size of canopy opening explained the magnitude and duration of initial summer streamflow surpluses and subsequent streamflow deficits, consistent with work on soil moisture dynamics of canopy gaps. In 1990, Gray, Spies, and Easter (2002) created experimental gaps in mature and old-growth forests in Oregon and Washington, including neighboring sites to the study basins, with gap sizes of 40 to 2,000 m^2 (tree height to gap size ratios of 0.2 to 1.0). The smallest gaps dried out faster during the summer than the largest gaps, with the highest moisture levels in the medium-sized gaps, which had less direct radiation and less vigorous vegetation than the largest gaps. In

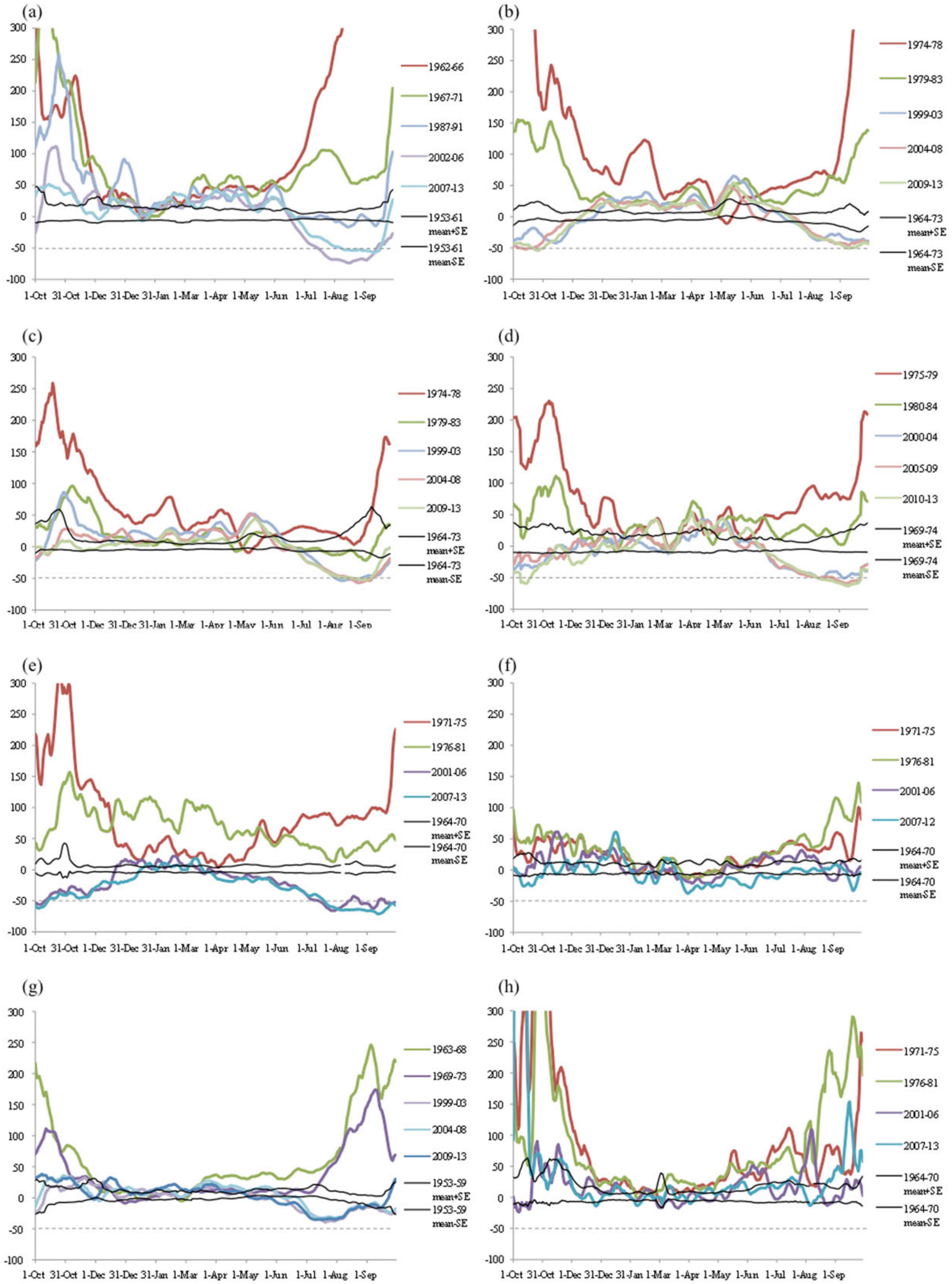

FIGURE 7 Percent change in streamflow by day of water year in 5-year periods after forest harvest and plantation establishment for eight pairs of basins. (a) AND 1 (100% clearcut 1962–66) versus AND 2 (reference), (b) AND 6 (100% clearcut 1974) versus AND 8 (reference), (c) AND 7 (50% cut 1974, remainder cut 1984) versus AND 8 (reference), (d) AND 10 (100% clearcut 1975) versus AND 2 (reference), (e) COY 3 (100% clearcut 1970) versus COY 4 (reference), (f) COY 1 (50% cut 1970) versus COY 4 (reference), (g) AND 3 (25% patch cut 1963) versus AND 2 (reference), (h) COY 2 (30% patch cut 1970) versus COY 4 (reference). Black lines represent the mean and standard error of the percent difference between the treated and reference basins during the pretreatment period. Dashed grey line is a 50% decline in streamflow at the treated basin relative to its relationship to the reference basin during the pretreatment period

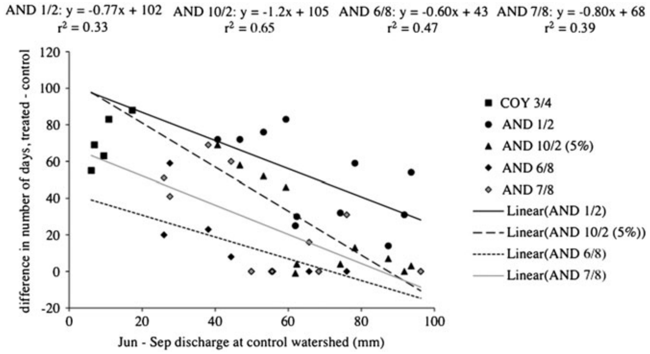

FIGURE 8 Difference in number of days in the first and fifth (AND 10/2) flow percentiles from 1995 to 2005, in basins with 25- to 40-year-old plantations relative to reference (old growth) basins. A value of 0 on the *Y*-axis indicates that the basin with forest plantation had the same number of days in the low flow percentile as the reference basin; a value of 80 indicates that the basin with forest plantation had 80 more days in the low flow percentile than the reference basin. Negative slopes of regression lines indicate that the duration of low streamflow increased in drier summers in the forest plantation, relative to the reference basin. The fifth percentile was used for AND 10/2 because only a few years had >0 day in the 1% category

late summer (September), volumetric soil moisture declined to 15% in references, 18% in small gaps, and 22% in each of the first 3 years after gap creation (Gray et al., 2002). Together, the paired basin and experimental gap results indicate that even-aged plantations in 8 ha or larger clearcuts are likely to develop summer streamflow deficits, and these deficits are unlikely to be substantially mitigated by dispersed thinning or small gap creation.

Relatively high rates of summer evapotranspiration by young (25 to 45 years old) Douglas-fir plantations relative to mature and old-growth forests apparently caused reduced summer streamflow in treated basins. Young Douglas-fir trees (in AND 1) had higher sapflow per unit sapwood area and greater sapwood area compared to old Douglas-fir trees (in AND 2; Moore, Bond, Jones, Phillips, & Meinzer, 2004). In summer, young Douglas-fir trees have higher rates of transpiration (sapflow) compared to old Douglas-fir trees, because their fast growth requires high sapwood area and because their needles appear to exercise less stomatal control when vapor pressure deficits are high. Leaf area is concentrated in a relatively narrow height range in the forest canopy of a forest plantation, whereas leaf area is distributed over a wide range of heights in a mature or old-growth conifer forest. In summer, these factors appear to contribute to higher daily transpiration rates by young conifers relative to mature or older conifers, producing pronounced reductions in streamflow during the afternoons of hot dry days (Bond et al., 2002). At sunset, transpiration ceases, and streamflow recovers. Hence, daily transpiration produces large diel variations in streamflow in AND 1 (plantation) relative to AND 2 (reference). Other factors, such as differences in tree species composition (Table 2), the presence of a hyporheic zone, or deciduous trees in the riparian zone of AND 1, may also contribute to differences in streamflow between these basins (Bond et al., 2002; Moore et al., 2004; Wondzell, Gooseff, & McGlynn, 2007).

Reduced summer streamflow has potentially significant effects on aquatic ecosystems. Summer streamflow deficits in headwater basins may be particularly detrimental to anadromous fish, including steelhead and salmon, by limiting habitat, exacerbating stream temperature warming, and potentially causing large-scale die-offs (Hicks et al., 1991; Arismendi, Johnson, Dunham, Haggerty, & Hockman-Wert, 2012; Arismendi, Safeeq, Johnson, Dunham, & Haggerty, 2013; Isaak, Wollrab, Horan, & Chandler, 2012). Summer streamflow deficits may also exacerbate trade-offs in water use between in-stream flows, irrigation, and municipal water use.

Reductions in summer streamflow in headwater basins with forest plantations may affect water yield in much larger basins. Much of the Pacific Northwest forest has experienced conversion of mature and old-growth forests to Douglas-fir plantations over the past century. Climate warming and associated loss of snowpack is expected to reduce summer streamflow in the region (e.g., Littell et al., 2010). Declining summer streamflows in the Columbia River basin may be attributed to climate change (Chang, Jung, Steele, & Gannett, 2012; Chang et al., 2013; Hatcher & Jones, 2013), but these declines may also be the result of cumulative forest change due to plantation establishment, fire suppression (Perry et al., 2011), and forest succession after wildfire and insect outbreaks, which kill old trees and promote growth of young forests (e.g., Biederman et al., 2015).

Air temperature has warmed slightly in the Pacific Northwest (0.6 to 0.8°C from 1901 to 2012; Abatzoglou et al., 2014), but water yields from mature and old-growth forests in reference basins have not changed over time. In the reference basins used in this study, we observed small changes in biomass and shifts in species dominance, consistent with changes expected as part of forest succession in mature and old-growth forests, but we did not observe large-scale mortality documented by van Mantgem et al. (2009).

This study demonstrates that plantations of native tree species produced summer streamflow deficits relative to mature and old-growth forest, consistent with prior studies in the U.S. Pacific Northwest (Jones & Post, 2004) and in mixed-deciduous forests in the eastern United States (Hornbeck, Martin, & Eagar, 1997). Research is needed to compare these effects to declining water yield from plantations of fast-growing non-native species in the southern hemisphere (Little et al., 2009; Little, Cuevas, Lara, Pino, & Schoenholtz, 2014; Scott, 2005; Farley et al., 2005). Despite summer streamflow deficits, young forest plantations in the Andrews Forest yield more water in winter, contributing to increased flooding (Harr & McCorison, 1979; Jones & Grant, 1996; Beschta, Pyles, Skaugset, & Surfleet, 2000; Jones, 2000; Jones & Perkins, 2010).

6 | CONCLUSIONS

Paired basin experiments are central to advancing long-term, integrated forest hydrology. Over the past half-century, many key paired-basin experiments (e.g., at U.S. Forest Service Experimental Forests and LTER sites such as Coweeta, Hubbard Brook, and Andrews) have evolved into headwater ecosystem studies, with detailed information about hydrology, climate, vegetation, biogeochemistry, and sediment export. These studies provide rigorous causal inferences about effects of changing vegetation on streamflow at successional time scales (multiple decades) of interest in basic ecology, applied forestry, and conservation. They permit researchers to distinguish forest management from climate change effects on streamflow. Paired-basin experiments are place-based science, integrate multiple disciplines of science and policy, and can dispel assumptions and conjectures such as equilibrium, common in hydrological modeling studies.

Long-term paired-basin studies extending over six decades revealed that the conversion of mature and old-growth conifer forests to plantations of native Douglas-fir produced persistent summer streamflow deficits of 50% relative to reference basins, in plantations aged 25 to 45 years. This result challenges the widespread assumption of rapid "hydrologic recovery" following forest disturbance. Widespread transformation of mature and old-growth forests may contribute to summer water yield declines over large basins and regions around the world, reducing stream habitats and sharpening conflict over uses of water.

Continued research is needed to examine how forest management influences streamflow deficits. Comparative studies, process studies, and modeling are needed to examine legacies of various past and present forestry treatments and effects of native versus non-native tree species on streamflow. In addition, long-term basin studies should be maintained, revived, and extended to a variety of forest types and forest ownerships, in order to discriminate effects of climate versus forest management on water yield and timing, which will be increasingly important in the future.

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