RENEWABLE RESOURCES JOURNAL

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WWW.RNRF.ORG

About RNRF

Purposes

The Renewable Natural Resources Foundation (RNRF) is an I.R.C. §501(c)(3) nonprofit, public policy research organization, founded in 1972. It is a consortium of scientific, professional, educational, design and engineering organizations whose primary purpose is to advance science, the application of science, and public education in managing and conserving renewable natural resources. RNRF's member organizations recognize that sustaining the Earth's renewable resource base will require a collaborative approach to problem solving by their disciplines and other disciplines representing the biological, physical and social sciences. The foundation fosters interdisciplinary assessments of our renewable resources requirements and advances public policies informed by science.

Members

RNRF's members are membership-based nonprofit organizations with member-elected leaders. The foundation is governed by a board of directors comprised of a representative from each of its member organizations. Directors also may elect "public interest members" of the board. Individuals may become Associates.

MEMBER ORGANIZATIONS

American Geophysical Union

American Meteorological Society

American Society of Civil Engineers

American Society of Landscape Architects

American Water Resources Association

Geological Society of America

Society of Environmental Toxicology and Chemistry

Society of Wood Science and Technology

Programs

RNRF conducts national conferences, congressional forums, public-policy briefings and round tables, international outreach activities, and a national awards program.

Renewable Resources Journal

The quarterly journal, first published in 1982, features articles on public policy related to renewable natural resources. It also includes news from member organizations, general announcements, meeting notices, and international conservation news. The journal is provided as a program service to the governing bodies of RNRF member organizations, members of the U.S. Congress and staff of its natural resources- and science-oriented committees.

News and Announcements

Renewable Natural Resources Foundation

Round Table Meeting on International Climate Negotiations in Paris

The World Resources Institute (WRI) hosted RNRF's Washington Round Table on Public Policy on October 2, 2015 at it headquarters in Washington, D.C. Jennifer Morgan, Global Director of WRI's Climate Program, presented "The Road To and Through Paris," a discussion of the context in which the upcoming United Nations Framework Convention on Climate Change (UNFCCC) negotiations in Paris are taking place. She also described key elements and challenges of a global agreement on reducing greenhouse gas (GHG) emissions.

The 21st session of the Conference of the Parties (COP21) to the UNFCCC will be the largest climate negotiation meeting since Copenhagen in 2009 (COP15). Since COP15, the "real economy" and political landscape have both shifted in ways that support a global agreement on climate change. Economically, there is increased understanding that economic growth and emissions reductions are not mutually exclusive. Politically, countries increasingly recognize that taking action on climate change is in their self-interest.

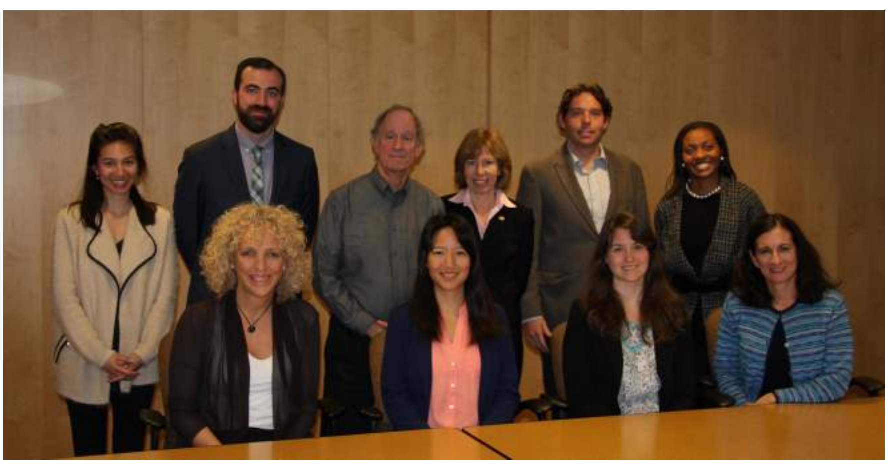
While the Kyoto Protocol, adopted in 1997 at COP3 as the first global agreement to mandate country-by-country GHG reductions, was top-down in nature, and the 2009 Copenhagen Accord was bottom-up, Paris will likely produce a hybrid of the two previous approaches. National contributions in the form of intended nationally determined contributions (INDCs) will likely be tied to an international, binding agreement. INDCs are the national post-2020 climate action commitments submitted by both developed and developing countries prior to COP21 in Paris. The three key elements of a global agreement, in Paris and beyond, are provisions for mitigation, adaptation, and support. The seven core functions of the Paris negotiations will be to:

1. Send a clear signal that the transition to a low-carbon economy is inevitable
2. Connect the global agreement to the "real economy" and "real people"
3. Provide transparency and accountability
4. Accelerate investment in low-carbon, climate-resilient economies
5. Build a basis for climate action that demonstrates fairness
6. Ensure that the vulnerable have the capacity to build resilience and adapt
7. Link to science with a sense of urgency

Negotiations are expected to produce a core legal instrument agreed upon by all 195 Parties to the Convention. This agreement will be associated with the INDCs, but the achievement of these contributions will probably be non-binding internationally. Instead, Parties will likely be subject to measuring, reporting, and verification requirements. Failure to meet stated goals will likely be punishable only through a "name-and-shame" approach.

To track global climate action, visit:

- CAIT Paris Contributions Map: http://cait.wri.org/indc/
- Climate Action Tracker: http://climateactiontracker.org/about.html



Pictured standing (L-R): Elizabeth Goldbaum (Geological Society of America), Ian McTiernan (American Institute of Architects), Howard Rosen (Society of Wood Science and Technology), Nancy Somerville (American Society of Landscape Architects), Whitford Remer (American Society of Civil Engineers), Natasha DeJarnett (American Public Health Association); seated (L-R) Jennifer Morgan (World Resources Institute), Jennee Kuang (Renewable Natural Resources Foundation), Melissa Goodwin (Renewable Natural Resources Foundation), Sarene Marshall (Urban Land Institute). Paul Higgins (American Meteorological Society) and Robert Day (RNRF) present but not pictured.

Register Today – 2015 Congress on Sustaining Western Water

Registration is now open for RNRF's 2015 Congress on Sustaining Western Water. The meeting will take place in Washington, D.C. on December 1-2. Delegates will assess the challenges of managing scarce water resources within the economic and regulatory framework of the western states. The congress will feature discussion of methods and opportunities to sustain water resources, including water transfers, land-use policy tools, and future scenario planning. Speakers will also address the importance of conserving water for forests, wildlife, and ecosystems. For more information, visit www.rnrf.org/2015cong.

New Blog - Renewable Resources Report

RNRF has launched a blog, the Renewable Resources Report. It serves as RNRF's platform for interdisciplinary discussion of natural resources and the environment. Visit *blog.rnrf.org* for regular updates on a wide range of environmental science and policy issues. Whether you are a general interest reader or subject-matter expert, RNRF welcomes your participation.

American Geophysical Union

Fall Meeting

Discover the latest in the Earth and space sciences at the 48th annual AGU Fall Meeting this December, when about 24,000 attendees from around the globe are expected to assemble for the largest worldwide conference in the Earth and space sciences. This year, the meeting runs from Monday through Friday, December 14-18, in San Francisco, California.

Attendees can learn about the latest research in fields as diverse as applications of unmanned aerial vehicles, changing climate and vegetation, habitable exoplanets, urbanization, changing glaciers, the Kuiper Belt, and more. The preliminary program includes more than 1,000 proposed sessions and 23,000 submitted abstracts.

For more information, contact AGU, 2000 Florida Avenue NW, Washington, DC 20009; (202) 462-6900, www.agu.org.

American Meteorological Society

AMS Launches New Website

The American Meteorological Society announces the launch of its new website, reflecting both a long overdue change and a means to better inform and serve the atmospheric, oceanic, and hydrologic science community. The site is designed to make it easier for the community to be more active and involved and includes updated content and navigation. The new website also features a brand new overall design.

Highlights of the new site include:

- Cleaner, easier navigation and stronger design elements
- Faster access to AMS programs, publications, meetings, activities, and research information
- More ways to get involved and stay informed
- More ways to advance careers

For more information, contact AMS, 45 Beacon Street, Boston, MA 02108; (617) 227-2425, www.ametsoc.org.

American Society of Civil Engineers

New ASCE Convention Adds More PDH Opportunities

ASCE's annual convention was conducted in New York City on October 11-14, 2015. Attendees at this year's convention obtained as many as 19.5 professional development hours (PDHs)—the most ever for ASCE's annual gather-

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Editorial Policy: The editors seek general interest articles concerning public policy issues related to natural resources management. Recommended maximum length of manuscripts is 4,000 words. All manuscripts will be reviewed by the editors and, where appropriate, by experts in the subject matter. (A "Guide for Contributors" is posted at RNRF's website.) ***Editorial Staff:*** Robert D. Day, editor; Melissa M. Goodwin, associate editor; Jennee Kuang, assistant editor.

ing. The convention offered attendees many ways to earn PDHs, including technical tours, short courses, technical programs, and plenary sessions.

Resilience was a recurring theme in many of the offerings. The history and heritage of New York City infrastructure was a key component of the technical tours and program, including a session on the Brooklyn Bridge.

For more information, contact ASCE, 1801 Alexander Bell Drive, Reston, VA 20191; (800) 548-2723, www.asce.org.

American Society of Landscape Architects

PARK(ing) Day

ASLA launched a coordinated effort with its local chapters to encourage everyone to participate in PARK(ing) Day on September 18 and share images of their "parklets" on social media using #ASLAPD.

Each year, PARK(ing) Day takes place on the third Friday of every September. Founded in 2005, PARK(ing) Day is a global, open-sourced event during which landscape architects and other professions transform metered parking spaces into temporary, miniature parks, or parklets.

The mission of PARK(ing) Day is to call attention to the need for more urban open space, to generate critical debate around how public space is created and allocated, and to improve the quality of urban human habitat

For more information, contact ASLA, 636 Eye Street, NW, Washington, DC 20001; (202) 898-2444. www.asla.org.

American Water Resources Association

2015 Annual Conference

AWRA's 2015 Annual Water Resources Conference is taking place in Denver, CO from November 16-19. Join AWRA for an engaging week of cutting edge presentations on timely water resources issues, and for dialogue with water resources experts from across the country and throughout the world.

This AWRA Annual Conference represents a perfect opportunity for practitioners and policymakers across the spectrum of the water resources community to share their experiences, learn from one another, and share their outlooks on and visions for the future of water resources. Take part in a program which will allow participants to take advantage of everything AWRA has to offer—four days of community, conversation, and connections that will benefit all water resource professionals. This event provides the opportunity to explore water resources challenges faced by water resources professionals around the world.

For more information, contact AWRA, P.O. Box 1626, Middleburg, VA 20118; (540) 687-8390. www.awra.org.

Geological Society of America

Annual Meeting in Baltimore, Maryland

More than 7,000 geoscientists presented abstracts at GSA's Annual Meeting and Exposition on November 1-4, 2015. This year featured several top-name speakers, and the meeting size and format were conducive to significant scientific conversations and making personal connections with expert resources.

Highlights included Feed Your Brain with Multimedia Earth Science Communicator James Balog, *Science* Editor-in-Chief Marcia McNutt, and NASA Chief Scientist Ellen Stofan; John P. Holdren, Director of the White House Office of Science & Technology spoke from the science policy perspective; and lunch with James Hansen was offered as part of the International "Bridging Two Continents" meeting in partnership with the Geological Society of China.

For more information, contact GSA, P.O. Box 9140, Boulder, CO 80301; (303) 357-1806. www.geosociety.org.

Society of Environmental Toxicology and Chemistry

SETAC Europe 26th Annual Meeting

SETAC Europe's 26th Annual Meeting will be held in Nantes, France from May 22-26, 2016. Under the general theme, "Environmental contaminants from land to sea: continuities and interface in environmental toxicology and chemistry," experts from academia, government and industry will share the most recent advanced knowledge in environmental sciences in order to improve chemical risk assessment and support current and future policies. Visit nantes.setac.org for details. Registration opens in mid-January.

For more information, contact SETAC, 229 S. Baylen Street, Pensacola, FL 32502; (850) 469-1500, www.setac.org.

Society of Wood Science and Technology

SWST Visiting Scientist Program

The SWST Visiting Scientist Program facilitates the exchange of knowledge between outstanding specialists in wood science and technology and interested persons at educational, industrial, or governmental institutions.

Many of the foremost wood scientists in the Society have participated in the program. Their presentations have consistently won praise from the hosts, and the scientists themselves have found the visits both stimulating and enjoyable. Visit http://www.swst.org/edu/vsp/ for details and consider participating in the program.

For more information, contact SWST, P.O. Box 6155, Monona, WI 53716; (608) 577-1342. www.swst.org.

The Road to Paris and Beyond

Rodney Boyd & Fergus Green

1. Introduction

In late 2015, representatives of close to 200 national governments and tens of thousands of civil society observers will come to Paris for the 21st Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC). It is widely hoped that this will be the conference at which a new international agreement is negotiated, setting out how countries will cooperate to tackle climate change, with a particular focus on the post-2020 period. The conference presents an important opportunity to advance global cooperation toward the urgent task of reducing global emissions of greenhouse gases and adapting to the impacts of climate change.

The purpose of this paper is twofold: (i) to set out certain critical matters of which a shared understanding needs to be built if successful climate cooperation is to occur (Part 3); and (ii) to propose certain key goals, principles, policies and institutions for action and collaboration on climate change, and explain how these can be embedded in the Paris agreement and more generally (Part 4). First, by way of background, we briefly describe the basic model and key features of the climate agreement that is likely to emerge in Paris, and identify some of the obstacles that could inhibit a successful outcome (Part 2).

This article is adapted from an August 2015 policy paper from the Centre for Climate Change Economics and Policy and the Grantham Research Institute on Climate Change and the Environment written by Rodney Boyd, Fergus Green, and Nicholas Stern. The complete paper can be accessed at http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2015/08/The-road-to-Paris-and-beyond.pdf.

2. The road to Paris: directions and obstacles

The conference presents an important opportunity to advance global cooperation toward the urgent task of reducing global emissions of greenhouse gases and adapting to the impacts of climate change.

a) Directions

The Paris COP is the next major event in a long history of such meetings, beginning in the early 1990s. The UN climate process has resulted in: the establishment of the UNFCCC (a framework agreement that mostly sets out broad principles, but with some commitments on emissions reporting); the more detailed, prescriptive, and centralized Kyoto Protocol, whose first commitment period ended in 2012; the less centralized and non-binding Copenhagen Accord/Cancun decisions in 2009/2010, which record climate change targets for individual countries to 2020; and the Durban process, beginning in 2011, which set in train the process of agreeing to a post-2020 framework by the end of 2015.

The French Government, which will host the Paris summit, has indicated that it will seek a "Paris Climate Alliance" as an outcome, based on four aspects:

1. A universal legal agreement, applicable to all countries.
2. National commitments covering control and reduction of emissions.
3. A financial aspect guaranteeing international solidarity with the most vulnerable countries.
4. An "Agenda of Solutions" aimed at implementing accelerators to ensure more ambitious progress beyond binding commitments.

The ongoing negotiations toward the first two aspects of this package can be thought of as a "hybrid" framework that mixes legally binding and non-binding elements, centralised and decentralised elements, based partly on a pragmatic assessment of what has worked better, and what less well, in previous international agreements (Bodansky and Diringer 2014). Specifically, there will likely be a central, universally applicable, legally-binding agreement, and this will be associated with "intended nationally determined contributions" (INDCs) by countries to restrain and reduce emissions, the achievement of which will be non-binding internationally.

Under this hybrid model, while the central agreement would be formally legally binding, the provisions within it relating to the key issue of greenhouse gas emissions control and reduction would merely be obligations of process/conduct, obliging participating parties to, for example, *submit*, and *record* a nationally-determined emissions reduction commitment—typically a quantified target—and perhaps also to *adopt* and *implement policies and measures* with a view to achieving their quantified commitment.[1] But the substance of those commitments will be "nationally determined," and the agreement is not likely to contain an internationally legally binding obligation on parties to *achieve* their quantified commitment *per se*.[2]

While many think that a superior outcome would be a more centralised regime, entailing legally-binding and enforceable obligations to achieve an internationally-negotiated domestic target, this is not necessarily the case, all things considered (IPCC 2014, ch 13; Green 2014). Participation in international processes and agreements is voluntary on the part of states, and different countries have different motivations and capacities for such participation. In current circumstances, we think a more flexible approach has helped, and will continue to help, increase engagement in the process (encouraging both participation in the agreement and greater ambition in commitments) by some of the most important countries (e.g. the United States, China and India), whereas a more centralised, legalistic, enforcement-oriented agreement would likely have alienated them (Green 2014; Stern 2014a).

On the other hand, some of the other centralised institutional elements in existing UN agreements have worked relatively well and could usefully be built upon in a new agreement. For example, there is widespread support among parties for a common framework, agreed rules and some centralised institutions, concerning the accounting, monitoring, reporting and verification (MRV) of countries' emissions. Moreover, many parties support the inclusion in the agreement of a long-term shared goal(s) and centralised processes and mechanisms to prompt higher ambition from parties over time.[3] Such elements would enable a greater degree of coordination and interaction among Parties than under the Copenhagen/Cancun model (Bodansky and Diringer 2014).

...INDCs...must be seen as initial contributions to an ongoing process of raising ambition over time.

b) Obstacles

Yet many obstacles remain on the road to Paris, and on the longer pathway toward an effective and equitable response to climate change. Most prominently, it is very likely that there will remain a significant gap between the aggregate of national commitments pledged toward the Paris agreement and those consistent with plausible 2°C pathways, meaning commitments will need to be ramped up in subsequent years. There are also concerns about how credible the non-binding pledges will be, necessitating an increased focus on the domestic (institutional, legal, policy and political) arrangements affecting the ability of countries to deliver on their commitments and to scale them up over time. And there are concerns over how equitable the agreement in Paris will be, and whether particular developed and developing countries are contributing equitably to the response to climate change.

Equity concerns have been particularly prominent in discussions of climate finance (and, to a lesser extent, non-financial forms of support) within the UNFCCC and could pose a challenge to reaching agreement in Paris. And yet these discussions focus on only a small part of the overall challenge of financing sustainable development over the next two decades—a key issue in tackling the two great challenges of this century, ending poverty and mitigating and adapting to climate change.

Finally, innovation in zero-carbon technologies and processes will be crucial to addressing these challenges, and yet inadequate investment in innovation hampers society's ability to do so.

3. The scale and pace of global action

Bearing in mind the likely shape of the Paris agreement and the obstacles that stand in its way, we now turn to set-

[1] A similar approach is expected with regard to adaptation and financial support (i.e. from developed countries for both mitigation and adaptation in developing countries), i.e. there may be obligations of process with regard to formulating national adaptation plans and financial strategies: see Morgan et al. (2014).

[2] This "nationally-determined" approach was agreed at COP19 in Warsaw and affirmed at COP20 in Lima. One suggestion as to how to achieve the non-binding aspects of the agreement that has attracted considerable interest is to record countries' commitments in a separate, non-binding document, such as a schedule to the main agreement. See, e.g., New Zealand (2014) and United States (2014).

[3] Again, it is envisaged by many that these institutionalised processes could extend not merely to emissions reduction commitments, but also processes for reporting on, and scaling-up over time, adaptation and financial support: see Morgan et al. (2014).

ting out what we see as the key elements of successful international climate cooperation, in Paris and beyond.[4]

a) Understanding the mitigation task

The first key to succeeding in international climate cooperation is to properly grasp the problem and understand what a successful response to it would ultimately require.

In 2014, global emissions were around 51GtCO_2e (Boyd et al. 2015).[5] The IPCC estimates the remaining "carbon emissions budget" consistent with 2°C trajectories as being in the region of 1,000–1,500GtCO_2 emissions. This is roughly equivalent to 40 years of global CO_2 emissions at the present annual level.[6] However, this budget would be exhausted well before that time if the long-term trend of accelerating annual emissions continues. Indeed, global emissions of around 50GtCO_2e into the 2030s could lock in temperature increases of around 3.5°C or more.

By contrast, in order to be on a plausible 2°C pathway, emissions should be:

- Around 35GtCO_2e in 2030[7]
- 20GtCO_2e or below in 2050
- Roughly zero (or "net zero"[8]), and possibly net-negative, before the end of the century[9]

Cutting global emissions from around 50GtCO_2e to 20Gt or below in 2050 is a cut by a factor of 2.5. Suppose also that world output were to grow by a factor of three over the period 2013 to 2050 (given an annual growth rate of around 3%). Under these assumptions, emissions per unit of output would have to be cut by a factor of 2.5 × 3 (i.e., by a factor of around 7 or 8) by 2050.

Emissions reductions on this scale imply a transition across society and the economy on a scale that would be appropriately described as an "energy-industrial revolution" (Stern 2015a).

b) Understanding the likely size of the Paris mitigation "gap"

It is very likely that there will be some gap between the INDCs pledged by countries in 2015 for the purpose of the Paris agreement and the emissions reductions needed by 2030 to stay on a plausible 2°C pathway. Recent announcements by a number of major emitters, including China,[10] the US,[11] and the EU,[12] are major steps in the right direction. However Boyd et al. (2015) concluded that based on these three announcements, the total INDCs submitted ahead of COP21 are unlikely to result in aggregate emissions that are consistent with the 2°C goal; a significant gap is likely to remain.

As of November 2, 2015, 128 Parties to the UNFCCC submitted INDCs. These 128 Parties were together responsible for 86.6% of global annual emissions of greenhouse gases (WRI 2015).

Due to the gap between necessary emissions reductions and the emissions implied by INDCs, they must be seen as initial contributions to an ongoing process of raising ambition over time.

c) Understanding the dynamics of transition

i) The benefits and opportunities

The transition to a low-carbon economy is part of a much larger set of processes of structural transformation that will characterize the global economy over the next two decades. These include: continued change in the balance

[4] When we are arguing that something should be in the Paris agreement itself, or could be advanced "on the side" of the Paris conference, we will refer to Paris explicitly.

[5] The EU, US and China account for around 46% of global emissions (23GtCO_2e in 2014). The next major contributions come from Asia (without China) with 16% and Africa and Eastern Europe/Eurasia on 9%.

[6] See IPCC (2013, ch 12). Note that there is a subtle interplay between probabilities of reaching certain trajectories (e.g. a chance of at least 50% or 66%) and accurate measurements of CO_2 emissions levels and its equivalents. Also bear in mind that data limitations restrict us to calculating "CO_2 budgets" as opposed to "CO_2 equivalent budgets." CO_2 is the most important driver of radiative forcing, the gas that is easiest to measure, and is long-lasting in the atmosphere.

[7] The IPCC pathway range is roughly 28-50GtCO_2e in 2030. We prefer to use a 2030 benchmark of about 35-36GtCO_2e: 35Gt is roughly the mid-point between the 10th percentile and median values given by the IPCC in its 2°C pathway range, since this requires less reliance on ambitious assumptions about the potential for negative emissions technologies in the second half of this century. See also UNEP (2014) which analysed model projections that limit global warming to less than 2°C (50-66% chance) but do not assume that net negative carbon dioxide emissions from energy and industry occur during the 21st century. These pathways have a median value of 36GtCO_2e in 2030.

[8] This reflects the reality that there are likely to be some anthropogenic emissions sources in sectors where emissions are difficult to eliminate altogether, and hence a need to offset these with expanded emissions sinks (e.g. from the land sector).

[9] Leaders at the G7 summit in Elmau in Germany in June this year acknowledged that we must reach zero emissions of carbon dioxide in the second half of this century. See Part 4 for more information.

[10] Chinese President Xi Jinping announced in November 2014 China's commitment to peak CO_2 emissions by around 2030, with the intention of peaking as early as possible, and to raise the non-fossil-fuel share of primary energy consumption to around 20% by 2030 (from the current level of ~10%).

[11] President Obama announced a target for the US of reducing their emissions by 26-28% by 2025 compared with the 2005 level.

[12] The leaders of the countries of the European Union decided at the European Council of 23/24 October 2014, to reduce emissions by 40%, 1990-2030 on the basis of domestic action.

of economic activity towards emerging market and developing countries; continued global population growth and urbanization (a projected 9.5 billion people on the planet and 6–7 billion of these in cities by 2050); and technological revolutions in information and communication technologies, materials, and biotechnology. Amid these changes, the world must also tackle ongoing and growing challenges of poverty, inequality, macroeconomic imbalances, ongoing problems in the financial sector, structural adjustment to technical and economic change, and grave pressures on natural resources, local environments and biodiversity.

The opportunities for tackling climate change alongside these other unfolding changes and challenges are profound. For example, the Global Commission on the Economy and Climate (2014) estimates that between now and 2030, the world will need to spend around US$6 trillion per year over the next 15 years on infrastructure—primarily in cities and energy systems, and primarily in the major emerging economies—for reasons other than to address climate change. The capital costs of this infrastructure, assuming it were to consist of incumbent (high-carbon and high-pollution) technologies and processes—“unsound” investments, in other words—would cost cumulatively around US $89 trillion to 2030. However, if “sound” investment decisions were made—using low-carbon, low-pollution, resource-efficient technologies and processes—the capital cost would be around US$93 trillion, and the additional capital expenditure would be more than offset by savings in operational costs (e.g. renewable energy infrastructure has lower operating costs since fossil fuels do not need to be purchased). Factor in the unpriced co-benefits of following the “sound” investment path—including greater energy security, and lower local pollution, congestion and waste—and it will be more attractive on economic, social and environmental grounds than the unsound path, before the climate mitigation benefits have even been considered (GCEC 2014, 2015; see also Green 2015).

...countries will generally have strong local incentives to be ambitious...in their efforts to reduce greenhouse gas emissions, irrespective of what other countries do.

This general, global conclusion is extremely important. It means that countries will generally have strong local incentives to be ambitious—and increasingly so over time—in their efforts to reduce greenhouse gas emissions, irrespective of what other countries do (GCEC 2014; 2015).[13]

Moreover, these costs and benefits are not static; they are changing all the time in response to factors such as the dynamics of learning and discovery, the scaling of new innovations, and the effects of new networks, norms and institutions. Innovation and scale (and their interdependence) hold especially great potential for further reducing the costs of clean technologies (Aghion et al. 2014; GCEC 2014; Stern 2015a). An excellent example of the dynamism of this kind of structural change is the advances made in solar photovoltaic (PV) energy installations. Extensive innovation and learning in solar PV have driven rapid cost reductions that have far exceeded forecasts. Solar PV module prices declined from around US$2,800 per watt (W) in 1955, to around US $100/W in the 1970s. Since then, the change has been remarkable: installed costs have fallen more than 50% since 2010 to around US$0.60–0.90/W currently (IEA 2014). The cost of energy that can be delivered from these devices is competitive (i.e. without the need for subsidies) in perhaps 79 countries (Stern 2015a).

Concerted innovation in zero/low-carbon technologies is likely also to produce beneficial knowledge spillovers that drive growth in other sectors (see Aghion et al. 2014). Empirical evidence suggests that low/zero-carbon innovation produces significantly more knowledge spillovers than innovation in incumbent, high-carbon technologies, and many of these spillover benefits accrue to the local economy (Dechezleprêtre et al. 2013, 2014).

We can reasonably expect the technology, economics, and politics of mitigation to become more favourable over time, meaning countries will find it increasingly feasible and desirable to increase their ambition.[14] This effect, moreover, is likely to be self-reinforcing, leading to “tipping” dynamics that ultimately produce new, low-carbon

[13] The Global Commission on the Economy and Climate finds that 50–90% of the emissions reductions needed to put the world on a plausible 2°C pathway by 2030 would be net beneficial. This is based on achieving the median value of the IPCC’s scenarios for holding to 2°C with a “likely” change, under which global emissions fall to 42Gt per year by 2030, relative to the IPCC’s business-as-usual baseline scenario, under which global emissions reach 68Gt by 2030 (see IPCC 2014, SPM, Figure SPM.4; NCE 2015). There will of course remain some actions necessary to reduce emissions that are not, at the time they need to be taken, locally net-beneficial, i.e. actions that do need to be justified primarily by their contribution to global change mitigation. This may be the case for some highly traded, carbon-intensive goods, for example (see Green 2014, 22).

path dependencies in technologies, institutions, political-economy patterns and social norms (Aghion et al. 2014; Green 2015; Heal and Kunreuther 2012).

ii) The barriers

But the process of reaching these desirable tipping points has been slow-going. There are many immediate, local barriers and challenges that often prevent the sound medium- and long-term decisions from being made. Many features of our technical, economic, political and social systems emerged in a high-carbon era where natural resources were treated as if they were effectively unlimited. These systems are subject to their own inertia and path dependencies that are difficult to dislodge.

Many of these barriers are institutional, regulatory, financial or technological—and these are often significant and intertwined. Well-designed and credible institutions, laws and policies are essential preconditions for ensuring that finance and technology are deployed in the most sound way.

Other barriers are distributional and political. Sound policies and investments will still have costs, even if the costs are exceeded by the benefits. And the way these costs and benefits are distributed matters greatly in political terms: the "losers" from decisions that favour low-carbon outcomes will often be concentrated in particular industries or sectors (e.g. fossil fuel industries and energy-intensive industries). Those sectors tend to be economically and politically powerful and have a vested interest in avoiding potential losses, and can mobilise effectively to block or dilute low-carbon reforms. Moreover, there are often legitimate concerns about the short-run impacts of structural reform on some households, workers and some communities, particularly those least able to manage them. The best response is to ensure that reform processes and policy packages are structured so that they are transparent, inclusive of under-represented interests, and equitable. In poorer countries especially, this means designing policy reform packages that also help reduce poverty as well as emissions. A further precondition of sound decision-making is thus an attentiveness to configurations of interest and power, and to questions of legitimacy and equity.

In order to get investment flowing in a sustainable way, it is important to have access to the right forms of finance, into the right infrastructure, and at the right time.

iii) Implications for international cooperation

Understanding these dynamics of transition helps to clarify where international cooperation could make a significant difference in accelerating national emissions reductions. Cooperation is needed, among other reasons: to help the finance and technology flow to the best projects, and to improve domestic institutions to that end; to ensure the processes and outcomes of this transition are equitable and legitimate; to generate political momentum for domestic reforms and counterweight the political power of vested interests; to spur innovation and cost reductions in new technologies and processes and their adaptation to local circumstances; and finally to provide direct incentives for mitigation in residual areas where local costs continue to outweigh the local benefits (Green 2015).

4. Goals, principles, policies and institutions for action and collaboration

a) Framing the mitigation task: appropriate long-term and medium-term goals

i) Net Zero emissions in the second half of this century

International climate cooperation should be organised around the long-term objective of achieving net zero emissions within the second half of this century, as detailed in the G7 Communique (G7 2015, 15), which is necessary for holding warming to within 2°C.

ii) Decarbonising electricity by mid-century

Given that in some sectors it will prove more difficult to drive emissions to zero, others will have to go to zero (or negative) well before the end of this century. Countries should therefore think strategically about the sequencing of their plans for phasing out emissions. Taking such a strategic approach enables medium-term goals to be set that

[14] For a developed country expression of this position, see: United States (2014); Stern, T. (2014). Todd Stern, the US Special Envoy on Climate Change, said recently that "because we see both political will and technology development increasing over time, we think the target we could put forward for 2030 five years from now will be measurably higher than a 2030 target we could put forward now. So we don't want to see low ambition locked in for 2030."

are consistent with the long-term net zero emissions goal.

Decarbonizing the electricity sector is the most urgent priority for decarbonizing the global economy (Fankhauser 2012; IDDRI/SDSN 2014).[15] As the UK experience of strategic decarbonisation planning is demonstrating (see, e.g., Committee on Climate Change 2013), it is reasonable to look to developed countries to decarbonize their electricity sectors well before the midpoint of this, and in so doing, fueling the innovation and cost-reductions in key technologies that will enable developing countries to follow closely behind them (Green 2014; Stern 2015a).

We see value in articulating this medium-term goal in the Paris agreement, though it could also be agreed among a smaller grouping of countries.

iii) Phasing out coal

Within efforts to decarbonise electricity, there is a strong case for international cooperation specifically to phase-out unabated coal (GCEC 2014; Collier and Venables 2014). Coal is the single largest contributor to global greenhouse gas emissions from energy.[16] Substituting away from coal would bring many attractive economic, fiscal, public health and environmental benefits to countries, quite aside from benefiting global climate efforts (GCEC 2014).

For these reasons, the Global Commission on the Economy and Climate has argued that high-income countries should commit now to end the building of new unabated coal-fired power generation and accelerate the early retirement of existing unabated capacity, while middle-income countries should aim to limit new construction now and halt new builds by 2025 (GCEC 2014, 301).

Again, we see value in articulating medium-term goals along these lines in the main Paris agreement, though in practice this is unlikely to happen in 2015. Initiative on these issues is more likely to come from a smaller coalition of committed countries, from which further endorsements and participation could grow. In this regard, the fourth aspect of the Paris process, which is focused on generating deeper commitments on specific issues among smaller groups of willing countries—along with sub-national governments, companies and civil society groups—would be the ideal setting in which to articulate, and build cooperative initiatives around, these medium-term goals.

Questions of equity and justice are intrinsically and instrumentally important...

b) Equity

Questions of equity and justice are intrinsically and instrumentally important in the international climate negotiations. If Paris is to be successful, countries will need to carry into the discussions a shared understanding of what a reasonably equitable approach to climate change would look like, and the empirical matters on which such an approach is predicated.

Insofar as equity relates to mitigation, a great deal of the transition to a low-carbon economy is rightly characterized as a beneficial opportunity for countries to improve their economies and societies in the context of dynamic changes in technologies, prices, institutions and norms, and that the benefits multiply through collaboration. Equity discussions regarding mitigation should be predicated on this shared understanding. It is false and misleading to characterize equity discussions as being entirely, or even mostly, about sharing "burdens" (Averchenkova et al. 2014; Stern 2014a, 2014b).

This framing allows us to interpret the principle, enshrined in the UNFCCC, of "common but differentiated responsibilities and respective capabilities" in a dynamic, collaborative, and opportunity-focused way. A promising way forward is to embrace the twin ideas of:

1. Rich countries embarking on a dynamic and attractive transition to low-carbon and climate-resilient economies in their own societies, involving strong and early emissions cuts, and strong examples.
2. Developing countries undergoing a similar transition, along a sustainable development pathway of their choosing, shaped by their own characteristics and endowments, where that transition is supported by finance, technology and know-how from developed countries and the private sector as a result of the latter's earlier/faster transition.

c) Dynamic elements of the Paris agreement

In the context of the expected "emissions gap," success in Paris will depend

[15] This is for several reasons: first, power generation is a major source of GHG emissions in most countries; second, low-carbon power generation is well understood and feasible, with many options available and costs coming down rapidly; and third, decarbonized electricity has an importantrole to play in reducing emissions in other sectors, especially transport (through battery-powered electric vehicles and rail), residential heating (through, for example, ground source and air source heat pumps), and some parts of industry.

[16] Coal combustion generated 44% of global CO_2 emissions from energy in 2011 (oil 35%; gas 20%; other 1%): IEA (2013).

largely on whether the new agreement contains elements that create pressures to scale-up ambition in the years following the Paris COP. These elements could usefully include:[17]

- Clear long- and medium-term shared goals based on climate science.
- Recognition of the gap between those goals and the commitments pledged under the agreement at that point in time, and provision for a regular, science-based assessment of aggregate emissions embodied in existing commitments and comparison with emissions reduction pathways for 2°C and 1.5°C.
- Acknowledgement that the Paris agreement is intended to be a dynamic instrument, embodying a shared expectation that parties' commitments must rise over time in order to bridge the emissions gap, and therefore that their 2015 INDCs are to be treated as starting points or minimum commitments, to be revised upwards over time.
- Encouragement of parties to adopt domestic institutions, laws and policies that can be expanded over time as conditions for reducing emissions become more favourable, and to explain how these enable the achievement of their INDCs and the progressive raising of ambition.
- Encouragement of parties to submit long-term decarbonisation plans soon after the Paris conference.
- A mechanism for a regular (e.g. five-yearly) major review of commitments at which time all parties are expected to raise the ambition of their commitment.
- Recognition in the agreement of diverse and significant contributions made by agents that are not parties to the agreement (e.g. subnational governments, cities, businesses), and the potential that exists for these agents to raise their ambition over time and in turn facilitate greater ambition by parties.

d) Domestic institutions, policies, and politics

An important catalyst for countries to raise their ambition over time is the presence of domestic institutions, laws, policies, and political configurations that are conducive to ever-greater ambition. In light of the above discussion about the opportunities and net-benefits associated with many low-carbon options, and the short-term barriers that block such sound decision-making, it will be important that countries:

...low-carbon innovation is currently dangerously underfunded and underdone around the world.

- Develop new, or utilise existing, state development / green investment banks to lower the cost of capital for low-carbon infrastructure (discussed further below in relation to finance) and institutions for zero-carbon innovation.
- Undertake nationally-appropriate reforms to improve the domestic investment climate and so lower the cost of capital for low-carbon projects and facilitate technological innovation.
- Design and sequence low-carbon policies and institutions that take account of the politics and political-economy of structural transition.

e) Finance for sustainable development

i) The financing task

Financial support for sustainable development in poorer countries (which are generally the most vulnerable to climate change) can promote better growth by creating healthier, more liveable and efficient cities; cleaner, more reliable and secure energy systems; and well managed and rehabilitated land, forests, and natural resources (GCEC 2014)—all of which is at the core of sustainable development and poverty reduction (Stern 2015a). Better, cleaner economic growth and sustainable development can reduce the risks of climate change by cutting GHG emissions through efforts to lower traffic congestion for instance, or to improve local air pollution and to be less wasteful. But it should also be complemented and reinforced through climate finance to support additional adaptation and mitigation.

In order to get investment flowing in a sustainable way, it is important to have access to the right forms of finance, into the right infrastructure, and at the right time. Delay is dangerous in the sense that the longer we wait to reduce emissions, the harder it is to remove them, and the more expensive it will be, which could crowd out valuable options. At the same time, infrastructure is long-lived, and so investment decisions made now will cast long shadows. Getting investment decisions wrong by investing in the wrong (high-carbon) infrastructure could jeopardise meaningful action.

Fortunately, there is no shortage of sustainable investment opportunities, and now is exactly the time to invest for low-carbon growth. In many developed countries, the private sector is sitting on record levels of savings and liquidity, and long-term real interest rates are low. Many resources are unemployed or under-employed. They can be invested in

[17] For further discussion of these kinds of elements, see Bodansky and Diringer (2014); GCEC (2014, ch 8); Green (2014); Stern (2014a).

activities and infrastructure that have strong economic and social rates of return and a long-term future.

The needed investments will be increasingly reliant on trustworthy domestic institutions and stable, long-term policy frameworks. Domestic institutions and policies in recipient countries are important to facilitate smoother access to private capital and overseas public financial assistance, and to increase the flow of public financial assistance over time in donor countries.

In these discussions, one critical element related to perceived riskiness of infrastructure investment is the cost of capital; that is, from an investor point of view, the cost of providing financing to an infrastructure project. For newer and more innovative types of green infrastructure projects more generally, the cost of capital is particularly sensitive to and dependent on government policy, which can introduce risk into decisions. The cost of capital of more innovative/ sustainable projects tend to be higher because there is a greater perception of policy risk, and investors may have less experience in financing such projects.

Public development banks, both national and international, have historically played an important role in mobilizing infrastructure development. In the transition to a low-carbon economy to date they have been critical (Mazzucato 2013), and they are likely to continue to be so. The presence of a national or multinational development bank can lower the cost of capital in an investment by reducing the perceived policy and governmental risks, for instance, as governments are less likely to change policy if a public entity has committed to a major project with a long time horizon. They can also provide financial products, convene parties, and provide specialist knowledge and other capabilities. And they have a wide range of experience with innovative risk-sharing instruments and dealing with complex infrastructure sectors, particularly in the energy, transport and industrial sectors —sectors that will receive a great deal of attention in the next 20–30 years. As a benchmark of the role of development banks, the UK Green Investment Bank is unique in that it will only target infrastructure to "green" and profitable projects; lending on commercial terms but bringing with it lower risks and crowding in private capital.

ii) Financing sustainable development: the role of Paris (December) in relation to Addis (July)

In Copenhagen (COP15) in 2009, and later embodied in decisions made in Cancun (COP16), developed countries agreed to collectively mobilise US$100 billion per year by 2020, from both public and private sources, for the purpose of financing climate change mitigation and adaptation in developing countries. The financial flows that will result from this initiative are significant, but are dwarfed by the funds required to put the world on a path to a sustainable, low-carbon and resilient economy.

A critical question is how the financial aspects of the agreement in Paris can complement and add to agreements shaped in Addis Ababa in July concerning the financing of sustainable development goals in the context of the need for very large infrastructure investments over the next 15 years. The climate finance should be complementary and additional to the finance for SDGs in a way that further enhances the sustainability aspects of the latter, and additional in the senses outlined below.

With regard to complementarity, there is clear and strong recognition in the draft SDGs of the importance of sustainability. Indeed the word "sustainable" appears in 11 of the 17 draft goals. In addition, the word "resilient" is used in connection with infrastructure and cities. Further, goal 13 (without the word sustainable) says explicitly "take urgent action to combat climate change and its impacts." Thus Paris climate finance should be defined in the context of a very clear emphasis on climate and sustainability in the SDGs.

With regard to additionality, the UN/ Paris climate finance could be additional to the SDG finance in the following four ways (Stern 2015b). First, it could generate specific projects and programmes that would not have otherwise materialized. Second, it could generate projects and programmes in areas of activity that wouldn't have otherwise been strongly covered in SDGs (possibly including adaptation and forests). Third, it could mobilise new sources of finances that would not otherwise have been forthcoming or available such as a slice of carbon taxation revenue. And fourth, it could raise the scale of overall ODA resources for climate which is additional to what has been previously committed to development.

f) Innovation

Innovation in general is hampered by market failures along the innovation chain.[18] Low-carbon innovation is further undermined by its particularly high capital requirements (especially for low-carbon energy generation) and by the mispricing of many existing goods and services central to climate change (especially the under-pricing of GHG

[18] These include: positive externalities; public goods aspects of knowledge/technology; imperfections in capital markets and risk-sharing; network infrastructure; and coordination problems. The problems associated with underinvestment can become more acute as technologies proceed into development, demonstration and early scale commercial deployment, just as the need for capital increases—the so-called "valley of death."

emissions[19]).[20] The global case for strong policies and investments in low-carbon innovation is therefore very strong (GCEC 2014; Stern 2015a). Strong policies and investments in innovation are also likely to facilitate increasingly higher ambition from countries of the kind that is needed to close the mitigation gap.

Yet low-carbon innovation is currently dangerously underfunded and underdone around the world. In particular, there is a major shortfall in the research and development and demonstration of clean energy technologies in both the public and private sector. This is not an area where the data allow us to be precise, but the general conclusion is clear: given the challenges we face, on climate change, energy insecurity, energy poverty, and air pollution, investments in energy R&D (and demonstration)—especially for renewable energy—are far too low (Stern 2015a).

The case for individual countries to support low-carbon innovation (e.g. through subsidies or direct government financing) is also likely to be strong, given the potential for high local knowledge spillovers, as discussed earlier. Nonetheless, there is a good case for greater international coordination on low-carbon innovation, since some of the public benefits from innovation do spill over into other countries, and since greater coordination could increase efficiencies through specialisation, scale and network effects (IEA 2012; GCEC 2014, ch 7; Aghion et al. 2014).

In light of these realities, international cooperation on low-carbon innovation could valuably include the following (Green 2014):

- Scaled-up public R&D funding, in the form of increased national funding coordinated internationally and, where appropriate, collaborative international partnerships—recognising that the latter can be complex (Anadon et al. 2011, ch 5; de Coninck et al. 2008). The Global Commission on the Economy and Climate (2014) has argued that the governments of the major economies should at least triple their investment in the R&D of clean energy technologies.
- Public-private regional networks focused on the development and demonstration of new and locally-adapted technologies and processes (GCEC 2014).
- Promoting public institutions and funding mechanisms to mobilise public venture capital for green innovators with high growth potential (Mazzucato 2013; Mazzucato and Perez 2014).
- Expanded and better coordinated deployment support policies, such as feed-in tariffs and renewable energy obligations (IEA 2012).

Importantly, these institutions should reflect the diverse needs and capabilities of different types of countries. High-income countries should focus more on frontier innovation, and other countries more on adaptive innovation and diffusion of new technologies and processes (Aghion et al. 2014).

The specific initiatives concerning innovation outlined above would be more suitably pursued outside the UN climate process, including by smaller groupings of states and non-state actors. However, the Paris conference could provide a political opportunity to advance and announce such initiatives, i.e. "on the side" of the formal process in Paris. As much as is possible, the Paris agreement could valuably acknowledge the factual context, principles and specific commitments concerning innovation discussed here.

[19] In addition to the under-pricing of GHG emissions, these include the mispricing of: natural capital and ecosystem services; energy (in)security; worker health and safety issues associated with fossil fuels; public health impacts of fossil fuels (especially air and water pollution); amenity impacts of fossil fuels; and natural resource scarcity and rents.

[20] The OECD and IEA have thus described low-carbon technology R&D as "twice a public good" (Philibert 2004); they could have gone further than "twice."

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What if California's Drought Continues?

Ellen Hanak, Jeffrey Mount, Caitrin Chappelle, Jay Lund, Josué Medellín-Azuara, Peter Moyle, & Nathaniel Seavy

Introduction

In 2015, California entered the fourth year of a severe drought. Although droughts are a regular feature of the state's climate, the current drought is unique in modern history. Taken together, the past four years have been the driest since record keeping began in the late 1800s.[1] This drought has also been exceptionally warm. Heat amplifies the effects of drought. It reduces snowpack, a major component of natural seasonal water storage. It decreases soil moisture, stressing natural vegetation and increasing irrigation demands. And it raises water temperatures, stressing fish and other species that live in rivers and lakes.

The combination of low flows and high temperatures make this a "drought of the future"—the type of drought California is increasingly likely to experience as the region's climate warms.[2]

Californians have been working hard to limit the drought's impacts on the state's economy, society, and environment. Since Governor Brown's January 2014 declaration of a statewide drought emergency, an Interagency Drought Task Force has met weekly to coordinate drought management.[3] The state and federal governments have funded emergency drought relief and water system investments intended to boost drought resiliency. Local water agencies are collaborating to lessen regional water shortages. And farmers, nonfarm businesses, and residents across the state are stretching available supplies.

This article is an excerpt from an August 2015 report published by the Public Policy Institute of California, a nonprofit, nonpartisan think tank. The complete report, including sections on drought impacts on cities and suburbs, farms, and rural communities, can be accessed at http://www.ppic.org/main/publication_quick.asp?i=1160.

> *The combination of low flows and high temperatures make this a "drought of the future..."*

These efforts have helped limit the economic impacts of the drought so far. But the experience is also revealing major gaps in California's preparedness to cope with the social and environmental impacts of extended, warm droughts. Too many decisions are being made on an emergency basis with the hope that the next winter will bring much-needed rain.

It would not be prudent to count on El Niño to end the drought.[4] To stand ready, the state needs to understand what impacts this drought has already had, what impacts to expect if it continues, and what steps may be warranted to prepare for this possibility.

This report provides insights into these questions. We focus on three areas of California's economy and society—cities, farms, and rural communities—and three acute ecosystem management challenges: waterbirds, fish, and forests. The analysis is informed by wide-ranging data sources and by conversations with officials, businesses, and stakeholders on the frontlines of drought management.[5] Table 1 summarizes the likely impacts and management challenges of continued drought, as described here.

Public discussions often frame drought policy in terms of trade-offs among different areas—for instance, cities versus farms, or farms versus fish. And to be sure, the drought is forcing difficult trade-offs. Drought preparedness cannot eliminate all costs and consequences of water scarcity, but it can help lessen vulnerabilities and enable society to handle trade-offs in a transparent and balanced way. Leadership from government, business, and civil society is needed to set priorities and navigate the trade-offs.

Water Availability in a Hot, Dry Time

During droughts, California relies on water stored in surface reservoirs and especially groundwater basins to help offset shortfalls in precipitation. This drought is stressing both types of reserves and affecting the amount and quality of water for farms, cities, hydropower, and the environment.

Impacts and Adaptations So Far

Surface Water

Thanks to an unusually wet 2011, the drought began with most surface reservoirs quite full. But these reserves are

Table 1. Likely impacts and management challenges if the drought continues.	
Water availability	
Runoff and storage	Reduced runoff (between 25-40% of average) due to low rainfall and snowpack. Fall reservoir storage at 50% of historic average. Impacts vary regionally depending on precipitation patterns
Deliveries and curtailments	Supply reduced for farms (8.5-9.0 million acre-feet/year) and cities (2.0-2.5 million acre-feet/year) compared to normal years. Central valley Project and State Water Project allocations remain at 2015 levels. Surface water shortages require extensive curtailment of water rights, including many senior pre-1914 and riparian rights. Hydropower generation remains at half of recent average, increasing energy costs ($500 million/year or ~2%).
Groundwater	Central Valley continues heavy reliance on groundwater. Excess pumping of 6 million acre-feet/year (with $650+ million additional energy cost for pumping). Increase in dry wells; acceleration of widespread land subsidence and damage to infrastructure.
Water quality	Low flows and high air temperatures cause widespread decline in water quality in rivers and streams. Low reservoirs make managing Delta salinity increasingly difficult.
Cities and suburbs	
Large metropolitan areas have reasonably secure supplies, but require continued conservation efforts and some new supply investments. Isolated communities with a single water source face shortages and require alternative supplies. Some water- and snow-sensitive industries that rely heavily on water (e.g., boating, skiing) face financial hardships, but not enough o dampen statewide economic growth.	
Farms	
Net water shortfall of 2.5-3.0 million acre-feet/year results in roughly 550,000 acres fallowed annually; economy-wide economic losses of more than $2.8 billion, loss of more than 10,000 full-time, part-time, and seasonal farm jobs, and more than 21,000 jobs economy-wide.	
Rural communities	
Increasing number of rural water districts and homes that rely on shallow wells need emergency assistance as wells go dry. Fallowing of farmland exacerbates poor air quality in some parts of the Central Valley and increases economic hardship in farmworker communities.	
Ecosystems	
Native fishes	Record-low flows and high temperatures continue to degrade habitat for native fishes. As many as 18 native fishes face likelihood of near-term extinction, including delta smelt, most salmon runs, and several species of trout. Economic losses for commercial and recreational fisheries.
Waterbirds	Dramatic declines in fall and winter habitat for waterbirds of the Pacific Flyway from reduced water for wetlands and flooded farmland. Bird populations reduced by limited food supplies and disease from overcrowding.
Forests	Extreme wildfire hazard due to high temperatures, dry conditions, and increased tree mortality in California's forests. Severe wildfires (comparable to the 2013 Rim Fire) occur, impacting local communities, watersheds, wildlife, infrastructure, and air quality. Risks of permanent loss of conifer forest ecosystems in burned areas.
SOURCE: See technical appendix Table A10 (http://www.ppic.org/content/pubs/other/815EHR_appendix.pdf) for details. NOTES: Assumes two or three more years of 2014 conditions. Reductions in water availability are relative to a normal rainfall year.	

now significantly depleted. Since 2014, two of the state's largest water providers—the Central Valley Project (CVP) and the State Water Project (SWP)—have dramatically reduced water deliveries to agricultural and urban customers.[6] Deliveries from many local projects have also decreased.[7] Hydropower generation, which relies on releases from reservoirs, is at its lowest level since 1977.

Reduced flows and high temperatures have also affected both the quantity and quality of environmental flows. Water releases from large Sacramento Valley reservoirs help keep salty ocean water from intruding into the Sacramento–San Joaquin Delta, thereby maintaining water quality for agricultural and urban exports and supporting habitat for estuarine fishes such as delta and longfin smelt. These reservoirs are also the primary source of cold water needed by salmon and steelhead that spawn just downstream of the dams. Other water releases—including treated discharges from wastewater facilities—are also important for maintaining environmental flows. Since early 2014, water agencies across the state were granted emergency permits to change the volume, timing, or quality of required outflows 35 times. As described below, insufficient environmental flow releases at above-normal temperatures have put some fish species on the brink of extinction.

The drought has also exposed weaknesses in the state's technical capacity to forecast the effects of management decisions under extreme conditions of high temperatures and low flows. This has complicated the management of cold water in reservoirs, among other things.

And the drought is revealing strains in the state's surface water allocation system. In California's "first-in-time, first-in-right" system of surface water rights, those with more recent—or junior—rights generally have lower priority in times of shortage. In 2014, the State Water Resources Control Board, which administers water rights and quality standards, ordered curtailment of water diversions by many junior water-rights holders for the first time since 1977; these orders were extended to more senior rights holders in 2015, and the board has also begun issuing fines for non-compliance. Some senior rights holders are challenging the board's legal authority to curtail their diversions.[8] The process has revealed significant gaps in information needed to administer surface water rights in a timely and transparent manner.[9]

It would not be prudent to count on El Niño to end the drought.

Groundwater

California's groundwater basins have considerably more dry-year storage capacity than its surface reservoirs, and many farms and cities are pumping additional groundwater to meet demands.[10] In a typical year, groundwater supplies about a third of total farm and urban water use. Since 2014, this share has exceeded 50%.[11]

Until recently, groundwater has been loosely regulated by the state. Many urban areas now have well-developed groundwater programs that regulate and charge for pumping to keep groundwater basins from experiencing long-term declines. In contrast, groundwater oversight in most agricultural areas is still limited, and many basins have experienced overdraft—excess pumping that reduces long-term reserves and lowers the water table. Consequences include sinking lands, higher pumping costs, drying up of wells, and drying of some rivers and wetlands fed by groundwater.

Extra pumping during this drought has exacerbated these symptoms of chronic overdraft. Land levels in parts of the southern Central Valley have been falling by more than half a foot annually, causing damage to various types of infrastructure, including bridges, reservoirs, and major water arteries like the Delta Mendota Canal.[12] Falling water tables are raising pumping costs and drying up drinking water wells in some rural communities. In many places, the additional groundwater now being pumped is of poor quality, which lowers crop yields. Conditions are particularly acute in the Tulare Basin—the major agricultural region that includes Fresno, King, Tulare, and Kern Counties—where groundwater supplies have been declining for decades.

Widespread concern over the trajectory of many rural groundwater basins led to the enactment of the Sustainable Groundwater Management Act (SGMA) in September 2014. The act requires water users in the most stressed basins to develop sustainable groundwater management plans by 2020 and reach sustainability by 2040.[13]

What if the Drought Continues?

To consider the impacts of continued drought, we assume that the dry, hot conditions of the past two years will persist for at least another two to three years. One caveat is that worse conditions—and worse impacts—are possible. For instance, 1977 was drier than the driest years of the current drought. Another caveat is that droughts often have considerable geographic variability. For example, 2015 saw record-low snowpack in the Sierra Nevada and near-record-low runoff in the Central Valley. Yet conditions in some North Coast communities improved dramatically thanks to isolated, intense winter and spring rains.

Continued drought will put additional stress on both surface and groundwater resources. Because the state's major Central Valley reservoirs have already drawn down most of the reserve built up by the 2011 rains, surface water deliveries from the CVP, SWP, and local projects will have to primarily rely on annual precipitation, as they did this past year. This means water deliveries will stay at least as low as currently—and possibly even fall lower—depending on decisions made regarding reservoir management for fish and wetlands and salinity in the Delta. Low flows and high temperatures will exacerbate declines in water quality in rivers and streams.

Groundwater will remain the primary drought reserve. But in some parts of the agricultural heartland, this will come at increasing costs, including more energy for pumping, more dry wells, reduced crop yields as water quality falls, and more damage to infrastructure from sinking lands.

Four Key Areas of Concern

The drought has left no part of California untouched, and continued drought will pose added challenges. The severity of threats varies across management areas, reflecting both underlying vulnerabilities to water scarcity and the degree to which managers have prepared for and adapted to drought. Cities and their suburbs, where most Californians live and work, have been adapting fairly well. Farms—the economy's largest water user—have also been adapting, but they are inherently more vulnerable. Rural communities are home to the most vulnerable Californians, facing both job losses and drinking water shortages. For this excerpt, we will focus on the crisis in California's ecosystems. Fish and waterbirds that rely on freshwater in rivers, estuaries, and wetlands are under extreme stress, and extinctions are likely. And trees in California's forests are dying at record rates, raising risks of devastating wildfires

Ecosystems

The most acute and severe impacts of this drought so far are on California's freshwater habitats and forested lands. These impacts stem, in part, from the severity of the drought and its combination of low flows and heat. More than a century of water and land practices have increased vulnerability by undermining the natural capacity of these ecosystems to handle occasional droughts.[14]

The environment doesn't have the same kinds of adaptation tools as other sectors—it generally can't pump more groundwater in dry times, for example.[15] But this troubling situation also reflects less investment in building drought resilience for the environment. California was unprepared for this environmental drought emergency and is now struggling to implement stopgap measures.

Waterbirds

California is home to diverse populations of ducks, geese, shorebirds, and herons and is an essential stopping point on the Pacific Flyway. Wetlands in northeastern California and the Central Valley provide winter habitat for more than five million waterbirds.[16] Twentieth century land development drained most natural wetlands, so these birds now rely on a network of managed wetlands—intentionally flooded areas in federal and state refuges and on private lands.[17] They also make extensive use of flooded farmland, most notably rice farms that are flooded in the fall and winter to break down rice straw.[18]

Impacts and Adaptations So Far

The drought has dramatically reduced the amount of waterbird habitat. Water deliveries to refuges—already tight in normal times—were cut by 25% or more, and the sharp drop in rice acreage reduced the availability of flooded farmland.[19] In addition to reducing food supplies, reduced wetland habitat increases risk of disease because crowding can decrease water quality.

So far, management actions and lucky timing of late spring rains have helped stave off major declines in bird populations. Close coordination between wildlife refuges across California in the past year has also helped ensure that limited water is distributed to wetlands when it can provide the greatest habitat value for birds.

Another promising effort is paying farmers to make small adjustments in the timing and duration of flooding fields. For modest amounts of money, these "pop-up habitats" can be strategically located to make the most use of limited water availability. The Nature Conservancy's BirdReturns is one such program, supported to date with philanthropic sources.[20] Federal funds support a similar program run by the Natural Resources Conservation Service.[21] These programs are prime examples of adaptively managing scarce resources to create a high return on investment.

If the Drought Continues

Risks of high bird mortality are increasing as the drought wears on. The Nature Conservancy estimates that refuges may face larger water cutbacks this coming winter, and that temporary wetlands in rice fields may be reduced by more than 85%.[22] Absent rains, food for ducks and geese will become critically scarce this coming fall precisely during the peak of bird migration.[23]

A continuation of current management efforts can help reduce ongoing drought impacts, but this will require dedication of both refuge water supplies and funds for purchasing farm water, which may become more costly as the drought wears on.

Native Fishes

California is home to 129 species of freshwater fish, two-thirds of which are found only in the state. One hundred of these fishes are either already listed as threatened or endangered under federal and state Endangered Species Acts or in decline and on their way to being listed in the future.[24] Many are highly vulnerable to low flows and higher water temperatures, and this drought is taking a major toll.

Impacts and Adaptations So Far

Since 2013, rivers and streams throughout the state have been at record or near record lows, with many waterways that would normally flow year-round becoming a series of disconnected pools or drying up. Higher temperatures have increased stress on fishes, most notably salmon and trout, as well as some amphibians. Survey counts for estuarine fish such as delta smelt and longfin smelt are at or near record lows.

Emergency management actions have included drought-stressor monitoring and rescue operations by the Department of Fish and Wildlife. In several key salmon and steelhead streams, the State Water Board has ordered some water users to stop diversions or to reduce groundwater pumping that was depleting surface flows.[25] But, as noted above, the board has also relaxed environmental flow standards on 35 occasions to accommodate urban and farm users.

While water managers have sought to manage the timing of flows in ways that benefit both fish and other water users, they have not always had that option. The drought has posed difficult trade-offs in managing scarce surface water, where goals of water supply, water quality, and fish flows often compete. This is best illustrated by ongoing efforts to preserve the 2015 cohort of winter-run Chinook salmon below Shasta Reservoir. Unplanned releases of warm water in 2014 caused a near-complete loss of wild-spawning winter-run eggs and fry.[26] Decisions made this year are likely to lead to a similar result, pushing this species very close or possibly to extinction. Restrictions on releases from Shasta Reservoir to try to correct these mistakes are affecting operations of Oroville and Folsom Reservoirs, reducing agricultural and urban supplies and making it difficult to meet salinity standards for water exports from the Delta.

If the Drought Continues

Eighteen native fish species appear to be at high risk of extinction in the wild, including most runs of salmon and steelhead and a diverse group of other fishes that reside in watersheds across the state.[27] Reasons include loss of rearing or spawning habitat due to reduced flows (an issue for all 18 species) and increased water temperatures (an issue for salmon, steelhead, and several other fish including delta smelt). The drought is also favoring conditions for invasive species that reduce the quality of habitat for some fish. For some salmon runs, an added stressor is the release of large numbers of hatchery-bred fishes, which can harm drought-stressed wild fish through competition, predation, or interbreeding that reduces the fitness of their offspring.

> *California's ecsosytems are in crisis.*

Beyond the fish rescue and monitoring efforts noted above, there is no comprehensive plan to address the potential for extinctions.

Near-term options for improving habitat in the wild are limited but could help in some cases. For instance, managing some smaller watersheds as refuges by restricting diversions and focusing restoration efforts could help some salmon runs. Better enforcement efforts may also help, especially where illegal diversions to marijuana farms and vineyards are depleting North Coast streams.[28]

And more generally, allowing a greater margin of safety on environmental flows for fish earlier in the season could improve chances of fish survival, though this would reduce availability of water for farms and cities. Creative approaches to acquire water and use it strategically, as in the BirdReturns case, could reduce conflict. Although the Department of Fish and Wildlife has tried to secure additional flows through voluntary agreements, the response has been limited. A sustained effort utilizing emergency funding to purchase water in selected watersheds may be needed to prevent extinctions.[29]

For many of these fish, it will also be prudent to develop a plan for protecting the species in captivity and rebuilding populations following the drought. This would mean expanding the state's program of conservation hatcheries—those specifically run to protect biodiversity. This would require rapid and substantial investments of resources because the state currently lacks the facilities, funding, and technical expertise to systematically pursue such an approach.[30] This approach would also be controversial because it would likely require shifting most current hatcheries away from producing fish for commercial and recreational fisheries, which are already taking a financial hit from fewer fish during this drought.[31]

Forests and Wildfires

Conifer and hardwood forests cover roughly a quarter of California. These forests are naturally wildfire prone, and a century of suppressing fires has made them much denser, increasing the likelihood of large, devastating fires.[32]

Impacts and Adaptations So Far

Hotter temperatures, moisture deficits, and insect infestations are killing trees at a rapid pace. These conditions lead to severe wildfires, posing significant threats to public safety, power lines and other infrastructure, water supply, air quality, and wildlife. Since the start of this drought, California has experienced two of the three largest fires in recorded history. When fires burn hot over large areas—as in the 2013 Rim Fire in and near Yosemite National Park—there is also a concern that conifer forest ecosystems may not recover.

The California Department of Forestry and Fire Protection's (CAL FIRE) strategy for this drought, in partnership with federal and local authorities, is to reduce the potential for large, destructive fires by suppressing fires as quickly as possible.

If the Drought Continues

California faces significant risk of more devastating fires like the Rim Fire over the next two to three years.

Given the scale of wildfire risk, CAL FIRE's fire suppression strategy is the only real near-term option. But this strategy could become harder as the drought wears on and forest conditions degrade. Management options to reduce severe fire risk will be of limited value in the short term, given the problem's vast scale. Fuel reduction efforts that can reduce fire intensity—including thinning and reintroduction of more frequent, low-intensity fires—require sustained efforts over large areas for decades. Although some efforts are underway on private lands, fuel reduction efforts on federal land—roughly half the forested lands in California—have proven difficult for a variety of reasons, including permitting.[33]

Building Drought Resilience

The ongoing drought has served as a stress test for California's water management systems, and continuing drought will test them further. Managers and businesses are employing an array of tools and strategies. Many of these have helped California reduce drought impacts. Others will need refinement and further investment.

Current drought actions fall into three general categories: those that are working well and may need minor improvements; those that are still works in progress, requiring support and refinement; and those that require substantial policy reforms or investments.

Historic investments in diversifying water supply sources and managing demands have yielded great benefits.

What's Working

- *Diversified water portfolios*: Historic investments in diversifying water supply sources and managing demand have yielded great benefits. Further investments could be aided by streamlined permitting.
- *Regional infrastructure*: Coordinated infrastructure development among multiple agencies has built regional diversity in water supplies and reduced vulnerability.
- *Coordinated emergency response*: Unprecedented coordination among state, federal, and local agencies has improved emergency response and reduced the economic costs of the drought.

Works in Progress

- *Mandatory conservation*: Although highly successful at reducing urban use, statewide conservation mandates can have unintended economic and social consequences if they are not implemented with some flexibility. They can reduce local financial capacity and appetite for new supply investments, and can cost jobs if they are not considerate of business water use. They can also convey an overly negative impression about urban water conditions in the state—potentially dampening future business investments.
- *Water pricing*: Many urban utilities have encouraged conservation with tiered water pricing, but they now face significant uncertainty about the legality of these rates. Low-income households are vulnerable if utilities make up for lost water revenues with higher fixed monthly fees. Legal reforms may be needed to support both efficient and equitable pricing.[34]
- *Rural community supplies*: Some domestic and small community water supplies will always be vulnerable during droughts, and emergency response has improved. But the mechanisms to report dry wells should be strengthened and response times shortened for getting water to affected residents. Continued progress is also needed to provide long-term safe water solutions to rural communities.
- *Groundwater management*: Groundwater is a vital drought reserve, and extra pumping has reduced the economic costs of the drought. The new Sustainable Groundwater Management Act will

boost the long-term drought resilience of California's farming sector and reduce negative impacts of unsustainable pumping. State and federal support for key technology and tools—such as groundwater models and well metering—can enable locals to move faster in implementing the law.[35] Addressing acute short-term impacts of pumping, such as infrastructure harm from sinking lands, may require charging new pumping fees or limiting new wells in some areas.

- *Water trading*: Water trading has helped reduce the economic costs of the drought so far, and it will be vital if the drought continues. But the market is not sufficiently transparent or flexible. Processes for approving trades are complex and often opaque. Little information is publicly available about trading rules, volumes, or prices.[36]
- *Waterbird management*: The risks to waterbird populations can be reduced by coordinating the management of water on refuge wetlands and flooded farm fields. State and federal investment in creative approaches can yield great benefits with limited water and funds.

Difficult Work Ahead

- *Improving the curtailment process*: In principle, California's seniority-based water-rights system is designed to handle droughts. But making it work well will require better information on water availability and use, clearer state authority, and more effective enforcement.
- *Modernizing water information*: To facilitate all facets of water management—including trading, curtailments, and environmental flows—the state will need to make major investments in the collection, analysis, and reporting of water information.[37] This includes updating models to consider the extreme temperature and flow conditions of modern droughts.
- *Managing wildfires*: The stopgap measure of suppressing fires during drought may work in the short-term, but a long-term strategy of improved forestry and fire management—with strong federal participation—is needed.
- *Managing surface water trade-offs*: The state and federal governments have not gone through the difficult exercise of defining and prioritizing objectives among competing uses of scarce supplies, especially when managing reservoirs. The difficulties of managing Shasta Reservoir to protect wild salmon highlight the need to do better forecasting and build in a margin of safety for environmental flows.
- *Avoiding extinctions of native fish*: Continued drought will likely lead to multiple extinctions of native fish species in the wild, and California lacks a plan to address this. More cautious strategies to save reservoir water for environmental flows may help, and purchasing water to boost flows could reduce conflicts. It may also be prudent to make immediate investments in conservation hatcheries.
- *Building environmental resilience*: Beyond stopgap measures, California also needs to invest in improving the capacity of our native biodiversity to weather droughts and a changing climate. This requires a plan and the funding to put it into action.[38]

Endnotes

1 See technical appendix Figure A1 (see full report) and related discussion.

2 J. Mount and D. Cayan. "A Dry Run for a Dry Future" (PPIC blog, May 27, 2015).

3 A list of state drought actions: http://ca.gov/drought/.

4 Some long-range models indicate that a strong El Niño may improve rainfall in California next winter, but the reliability of these forecasts is low and the relationship between El Niño and precipitation in Northern California is weak. See D. Cayan and J. Mount, "Don't Count on El Nino to End the Drought," (PPIC blog, July 9, 2015).

5 We spoke with close to 50 individuals, representing 11 state and federal agencies, urban water agencies in five regions, agricultural water supply, food processing, and lending activities, and nonprofits working on rural water supply and environmental management.

6 CVP settlement and exchange contractors, a group of agricultural districts that usually get 100% of their contractual amounts, received 75% in 2014, and may receive just 55% in 2015. CVP urban customers south of the Delta, including Santa Clara Valley Water District, were cut from the usual 75% to 25%. Some CVP agricultural contractors have received 0% of their contracts since 2014 (down from a 2008–13 average of 64% for those located north of the Delta and 39% for those located south of the Delta). SWP Feather River Settlement Agreement holders, agricultural districts that usually get 100% of their contracts, got only 50% in 2015. Regular SWP urban and agricultural contractors, who received an average of 50% from 2008–13, got just 5% in 2014 and 20% in 2015.

7 For instance, the Los Angeles Aqueduct, which conveys water to LA from Mono Lake and Inyo County, is projected to deliver just 32,000 acre-feet this year: the lowest since its construction (mostly from pumped groundwater rather than snowmelt runoff). Deliveries since 2008 have averaged 150,000 acre-feet/year.

8 See for instance D. Kasler and R. Sabalow, "Water Rights Ruling a Setback for California Drought," *Sacramento Bee*, July 10, 2015.

9 See for instance F. Nirappil, "California Drought: Regulators Say First Water Diversion Prosecution Aided by Detailed Records," *Contra Costa Times*, July 23, 2015. For a discussion of information needs, see J. Mount et al., *Policy Priorities for Managing Drought* (PPIC, 2015).

10 California's groundwater basins hold at least three times as much usable water as state surface reservoirs, and a large share of surface reservoir storage is for seasonal uses, not carryover storage for dry years. See J. Lund et al., *California's Water:*

Storing Water (PPIC, 2015).

[11] For groundwater use from 1998 to 2010, see C. Chappelle et al., *Reforming California's Groundwater Management* (PPIC, 2015). Recent estimates of more than 50% are based on work by R. Howitt et al., described in technical appendix Table A5 (see full report).

[12] For a general overview, see California Department of Water Resources, *Summary of Recent, Historical, and Estimated Potential for Future Land Subsidence in California*, 2014. During the drought of the late 2000s, the US Geological Survey found land sinking, or subsidence, rates ranging from 1 to 21 inches over a three-year period. These rates are likely to be accelerating with the pumping now occurring. (M. Sneed et al., *Land Subsidence along the Delta–Mendota Canal in the Northern Part of the San Joaquin Valley, California, 2003–2010*: US Geological Survey Scientific Investigations Report 2013-5142.) For a discussion of impacts to Sack Dam, where continued subsidence will cost local farmers $10 million to move water, see "California farmers dig deeper for water, sipping their neighbors dry," *New York Times*, June 5, 2015. Subsidence-related damage to a bridge over a canal in Fresno County will cost $2.5 million to repair. See "Groundwater pumping causing Central Valley bridges to sink," KSFN, July 21, 2015.

[13] Basins identified as critically overdrafted need to meet this timeline. Other priority basins have an additional two years to adopt and start implementing their plans. The law gives local agencies the authority to implement the plans, including the ability to measure use and charge fees for pumping. The State Water Board can intervene if it deems local efforts inadequate.

[14] See chapter 5 of E. Hanak et al., *Managing California's Water: From Conflict to Reconciliation* (PPIC, 2011).

[15] One exception is wetlands, where groundwater can replace lost surface flows.

[16] See Central Valley Joint Venture (http://centralvalleyjointventure.org), accessed July 9, 2015.

[17] Managed wetlands account for a relatively small share of water use in California: typically 1.5 million acre-feet, or less than 2% of the total (J. Mount et al., *Water Use in California*, PPIC, 2014).

[18] N. Seavy et al., "Farms That Help Wildlife," (PPIC blog, April 21, 2015) and J. Mount et al., *California's Water: Water for the Environment* (PPIC, 2015).

[19] Rice acreage fell from an average of 567,000 acres in 2010–13 to just 434,000 acres in 2014 (-24%), and acreage in 2015 is projected at 385,000 (-32%) (US Department of Agriculture, National Agricultural Statistics Service, California Acreage Reports, accessed July 28, 2015). Tight water conditions are also reducing the acreage that gets flooded post-harvest.

[20] The Nature Conservancy California, "Precision Conservation" (http://www.conserveca.org/our-stories/all/7-spotlight/132-precision-conservation#.VZ8Dl_lVikq), accessed July 9, 2015.

[21] The program is called the Critical Waterbird Habitat Fund Pool. Whereas the BirdReturns program uses an auction to determine payments, the NRCS program makes fixed payments.

[22] Personal communication, Jay Ziegler, The Nature Conservancy, July 8, 2015.

[23] Unpublished modeling work, Ducks Unlimited. This modeling was specific to ducks and geese, but the shortfall in habitat could impact shorebirds as well.

[24] P.B. Moyle et al., "Rapid decline of California's native inland fishes: a status assessment." *Biological Conservation*, 2014, Vol. 144(10): 2414–2423; P.B. Moyle et al., "Climate change vulnerability of native and alien freshwater fishes of California: a systematic assessment approach," *PLoS One* 2013; and P.B. Moyle et al., *Fish Species of Special Concern in California. Sacramento*: California Department of Fish and Wildlife, 2015.

[25] This includes periodic curtailment of diversions on Antelope Creek and Deer Creek since 2014 to support spring-run Chinook salmon, and recent orders to stop groundwater use on landscapes on several creeks in the Russian River watershed to support coho salmon and steelhead.

[26] J. Mount, "Better Reservoir Management Would Take the Heat Off Salmon" (PPIC blog, June 23, 2015).

[27] See technical appendix TableA9 (see full report) and related discussion for a list of the species, the methodology used for this assessment, and a discussion of potential management actions.

[28] C. Chappelle and L. Pottinger, "California's Streams Going to Pot from Marijuana Boom" (PPIC blog, July 23, 2015).

[29] The development of native fish-oriented flow regimes below many dams would also be beneficial. See T. Grantham et al., "Systematic screening of dams for environmental flow assessment and implementation," *Bioscience*, 2014, Vol. 64: 1006–1018.

[30] Some species are already kept in captivity with the goal of preventing extinction (such as delta smelt, Central Coastcoho salmon, McCloud River redband trout, and Central Valley winter-run Chinook salmon). The use of conservation hatcheries will be more difficult for fish that do not already have captive populations or populations that live outside of their native range. See technical appendix Table A9 (see full report) and related discussion.

[31] For some fishery sector statistics, see technical appendix Figure A8 (see full report) and related discussion.

[32] P.J. McIntyre et al., "Twentieth-century Shifts in Forest Structure in California: Denser Forests, Smaller Trees, and Increased Dominance of Oaks," *Proceedings of the National Academy of Sciences*, 2015, Vol. 112(5): 1458–1463.

[33] The federal government owns 55% of forests and woodlands in California (California Department of Forestry and Fire Protection: Forest and Rangelands 2010 Assessment). On permitting challenges on federal lands, see M. North et al., "Constraints on Mechanized Treatment Significantly Limit Mechanical Fuels Reduction Extent in the Sierra Nevada," *Journal of Forestry*, 2014, Vol. 113(1): 40–48.

[34] See E. Hanak et al., *Paying for Water in California* (PPIC, 2014).

[35] The Center for Irrigation Technology at Fresno State University estimates that only about a third of wells are now metered; such metering can be useful for efficient on-farm water use as well as groundwater basin management. See the interview with David Zoldoske in L. Pottinger, "The Challenges of Getting More Crop per Drop," (PPIC blog, July 28, 2015).

[36] See the discussion on water markets in the technical appendix (see full report).

[37] Some promising recent changes in this direction include new reporting and measurement requirements for surface water diversions. See H. McCann and C. Chappelle, "Drought Bills: Small Changes, High Impact" (PPIC blog, June 30, 2015).

[38] One promising approach to environmental drought planning comes from Australia. See J. Mount et al., *Policy Priorities for Managing Drought* (PPIC, 2015).

On MOOCs

Louis L. Bucciarelli & David E. Drew

In the past few years, leading, world-class universities have initiated massive online open courses (MOOCs) with the goal of providing high-quality educational experiences, free, to people around the world. Now a variety of institutions offer such courses, some for free, some for a fee.

MOOCs may reshape higher education. Or they may not last long in their present form.

Introduction

MOOCs have provoked new thinking about strengths and weaknesses in traditional undergraduate education as well as how best to take advantage of the technology of online learning

At this stage, it is not at all clear how the ideas, methods, and structure of MOOCs might be deployed and used to advantage by teachers[1] and students. Some see an opportunity to significantly cut the costs of postsecondary education as, in an ideal form, a MOOC has little need for staffing once the video lectures, readings, and exercises have been posted online.

We focus on the MOOC as a phenomenon of online learning that is unique in several ways: First, the courses are offered free of charge, for now at least and for the most part. Second, they are built on existing courses at a variety of colleges and universities and designed for undergraduates at these institutions.

The online courses are produced and made available through independent providers (e.g., Coursera and edX) that operate an online platform for access to and enrollment in the courses. They serve as a clearinghouse for MOOCs offered by universities all over the country and indeed the world, from Johns Hopkins to Peking University, the University of Edinburgh to the University of Michigan.

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MOOCs have provoked new thinking about strengths and weaknesses in... undergraduate education.

Claims

Providers trumpet a new approach to education, claiming the MOOC dramatically expands access to high-quality instruction for study and professional growth. Coursera, for example, bills itself as "an education company that partners with the top universities" to provide "millions of students," with a "world-class education that has so far been available to a select few...to empower people...improve their lives, the lives of their families and communities they live in."[2]

On the home page of edX, one reads that it "was created for students and institutions that seek to transform themselves through cutting-edge technologies, innovative pedagogy, and rigorous courses," and it "present[s] the best of higher education online, offering opportunity to anyone who wants to achieve, thrive, and grow."[3]

Thomas Friedman (2013) of the *New York Times* sees a day

> *where you'll create your own college degree by taking the best online courses from the best professors from around the world – some computing from Stanford, some entrepreneurship from Wharton, some ethics from Brandeis, some literature from Edinburgh – paying only the nominal fee for the certificates of completion. It will change teaching, learning and the pathway to employment.*

Hard Questions

We first describe an "ideal" MOOC and subject it to critique. This idealization is meant as an extrapolation to an extreme along an axis of increasing automation of the MOOC—a strawman.

In what ways might the ideal form of an online course divert interest and ef-

[1] We use "teacher" to refer to professors and scholars for students at all levels.
[2] www.coursera.org/about/
[3] www.edx.org/about-us

fort from valued and true pedagogical and curricular reform, or raise false hopes about possibilities for solving problems of access and affordability? In its thrust toward democratization of education, might not what's construed as "education" via MOOCs be but a shallow imitation of what goes on in "residential" (face-to-face) learning?

Our objective is to test how the ideal MOOC might live up to the providers' lofty ambitions. We argue that for more mature students (e.g., those who already have a degree) the MOOC might work in its present form, depending on the registrant's motivation and interest. For younger students (e.g., undergraduates) —the intended audience inferred from the rhetoric—we doubt the ideal MOOC will work at all.

The Ideal MOOC

The ideal MOOC offers a set of professionally produced, videotaped lectures that can be viewed anytime, anywhere; they come in 5- or 10-minute segments, are professionally done, and may include well-crafted simulations and artfully done illustrative material from relevant sources. The video can be paused to be viewed over and over, and may be accompanied by a scrolling of the lecturer's words. No notes need be taken.

The ideal MOOC takes advantage of the interactive capabilities of digital media in the graphic simulation of phenomena and laboratory tasks. Exercises are included both to actively engage the student and to test comprehension and progress. A distinct advantage of these exercises is that feedback can be instantaneous. In addition, the student may have more than one opportunity to get it right before the correct response is revealed.

Assessment of a student's progress and overall performance relies on machine grading. Some MOOCs may set out scoring rubrics for student evaluation of one another's work; in the ideal case, no faculty need be involved once rubrics have been posted online.

The ideal MOOC also offers a forum for discussion, in which the student seeking clarification can pose a question and another student respond. Participation in the forum of the ideal MOOC is limited to students; there is no need for faculty intervention once the rules and protocol have been promulgated.

For economy of development effort, sequencing of lessons follows the path laid out in the syllabus of an established and proven residential course, but the start date need not be tied to the beginning of a semester or term.

MOOC students [already] have very high levels of educational attainment.

In summary, with the ideal MOOC,

- lecture video clips are available online anytime, anywhere;
- students benefit from instant feedback on exercises, opportunities to redo their work, and peer evaluation;
- a self-directed discussion forum engages students with one another;
- flexibility in start date frees the courses and students from seasonal constraints; and
- there is no need for faculty or staff to intervene.

If one conceives of the MOOC in this form, then one is justified in claiming an audience of millions and, with no need for faculty or staff to intervene, the ideal MOOC promises to dramatically reduce the cost of a university education.

Critique

There are several things wrong with the "ideal MOOC:"

- It pays little heed to who the students are and cannot accommodate the need for face-to-face interaction among students and teachers.
- It treats knowledge as information simply to be conveyed from teacher —or rather server—to student.
- It relies on very constrained forms of exercises to engage students and assess their performance.
- There is very little information about how different, independently developed MOOCs relate or might be brought together to constitute a coherent program.
- It says nothing about the educational system within which the MOOC might be deployed (for better or worse).

We elaborate on these deficiencies in the following sections.

Students

The ideal MOOC is characterized by a number of challenges to the student experience.

First, it fails to take account of the importance of face-to-face interaction between student and teacher. The discussion forum offers the opportunity for student-initiated questions and commentary, but in its ideal form—indeed, in its contemporary form—it is, at best, an impoverished imitation of what is encouraged in a residential classroom. Early data show that only a small percentage, on the order of 3%, of the total number of registrants actively participate in a discussion forum by posting questions, commenting, or debating with one another (Breslow et al. 2013).

The lack of faculty or staff intervention in the ideal discussion forum won't work. Prompting, oversight, and monitoring are needed. But what should these entail? What are the best ways to encourage the substantial, the reflective, the probing? And to do so in a timely fashion? When, if ever, should the window on comments be closed? How responsive ought staff be to direct queries?

Second, a well-crafted suite of exercises can give students the sense that they are being personally attended to, but it is all in terms set by the machinery. The student is given well-posed questions and expected to respond in a limited and defined number of ways. Correct selections are rewarded with a green check mark.

Third, there is a significant discrepancy between the promotional words of providers about the types of students who take advantage of MOOCs and the reality. The providers imply that most MOOC students are like those populating the university's residential course of the same name. But the distribution of MOOC registrants shows an average age of about 30 and a significant number more than 50 years old. For example, a former high school English teacher in her 80s, Myra Lesser of Great Neck, New York, wrote in a letter to the *New York Times* (December 12, 2013):[4]

> *A little over a year ago, I read about Coursera in The Times, went to the website and signed up for some courses. I had no intention of seeking any credit or taking exams, but I did watch the lectures and read a great deal of the supplemental material.*
>
> *Hurricane Sandy arrived and I was housebound, but constantly engaged and enlightened by always interesting, often positively brilliant lectures. The courses gave depth to my understanding of current global realities and frequently helped me look at today's world in an entirely different way. I have many friends who are similarly enthusiastic. In short, I think these courses are a great benefit to huge numbers of people.*

In May 2013, the age distribution of registrants in all MITx courses showed an average age of 30.9, and for students in an online MIT freshman physics course, 31.3 years,[5] more than half of whom had a bachelor's or higher degree (Belcher 2013).

The University of Pennsylvania surveyed approximately 35,000 students who had enrolled in at least one of 32 MOOCs offered on the Coursera platform and reported that "Across all geographic regions, MOOC students have very high levels of educational attainment: 83.0% of students have a post-secondary degree (2 or 4 years), 79.4% of students have a Bachelor's degree or higher and 44.2% report education beyond a Bachelor's degree" (Christensen et al. 2013, p. 4). The authors also found that 60% of the students were over 30 years of age and 10% were over 60. The majority (62.4%) were employed full-time or self-employed, and 13.4% reported being unemployed or retired.

Faculty and students who see learning as an interactive process...will not find MOOCs...attractive.

Another way MOOC students differ from residential undergraduates is in their much lower rate of perseverance. Some 44,000 individuals registered for the 8.02x physics course; the second exam was taken by roughly 2,500 students; and 1,715 completed the course and received a certificate. Similarly, only about 7% of the students who registered for 6.002x, the electrical circuits course, earned a certificate. The large percentage of "listeners" and dropouts is characteristic of MOOCs.

Information vs. Knowledge

We distinguish between information as facts (e.g., the periodic table, universal constants) and as narrative (textual presentation of concepts, principles, and methods), and knowledge as the constructive renderings of information by an individual in a particular context confronted with a particular question or problem. MOOCs are best suited to the one-way transfer of information from server to student.

A textbook contains facts and narrative information that can be stored in bits on a server and transmitted to students. No ambiguity here. But knowledge—a grasp of what that information means, implies, and how it might be used—will vary from one individual to another.

Science and engineering "knowledge" is deceptively well suited for packaging and transmission via a MOOC as information, with the expectation that all students will know in the same way. Exercises that admit but a single correct answer imply as much. The deception is in the prevailing notion that textbook science and engineering theories, concepts, and methods are fixed for all time and beyond questioning. As such, the ideal MOOC's rendering of science and engineering "knowledge" is thoroughly decontextualized, presumed as relevant to a student in rural India as to her cousin enrolled at MIT. Moreover, it fails to take account of a registrant's prior experience; norms and values instilled through previous schooling; a registrant's broader cultur-

[4] The letter is available at www.nytimes.com/2013/12/17/opinion/online-courses-high-hopes-trimmed.html?_r=0.
[5] The count of students in the freshman physics course (8.02x) was restricted to those who remained engaged in the course past the second exam.

al context(s) (e.g., socioeconomic background, demographics, language skills) and how they differ, including in technical access; or individual motivations and interests.

Faculty and students who see learning as an interactive process—more like kindling a flame than depositing stores of knowledge in a bank—will not find MOOCs very attractive.

Exercises and Evaluation

One of the advantages claimed for the ideal MOOC is its ability to respond instantly to a student's submission of a solution to a problem posed online. This is true, but only for a type of problem that reinforces the image of knowledge as information to be conveyed from teacher to student.

With thousands of students enrolled in a MOOC, the opportunity for exchange with the instructor is severely limited, if not wholly absent. In a residential university science or engineering course the instructor or a teaching assistant has the opportunity to read through and evaluate a student's method of solution and offer feed-back (admittedly, not all do). The same sort of exchange is not possible for the student of an ideal MOOC.

MOOC exercises that require an essay response would seem to require a reading by staff. But even here the connection with the student is problematic. It is characteristic of the MOOC to constrain staff to communicate with students through the discussion forum, where the postings are accessible by all.

Program

The stand-alone MOOC may work very well for a mature student seeking to brush up on a subject or to broaden understanding in an area, but for students of university age and interests, a course is but one component of a program of studies leading to a degree. And on that subject, the ideal MOOC is silent.

One can imagine how a set of MOOCs in a particular domain, chosen from the rich menus of offerings of two or three prestigious universities, might be strung together on paper for degree certification by the universities themselves or a third party, but this falls far short of the learning experience at a university. A patchwork of courses does not make for a coherent program.

A patchwork of MOOC courses does not make for a coherent program of study.

Alexander Astin (1999), a leading scholar of higher education, has noted that, in the voluminous research about college impact, course content turns out to be a small contributor to the growth that students experience as undergraduates. Opportunities for growth, understood in a traditional sense, are limited online.

A residential student's learning experiences may include project-based learning, collaborative design tasks, public service, study abroad, research in a professor's lab, and substantial advising. And we should not ignore the connections students make with their peers, social as well as intellectual, as members of a community. All this is missing from the MOOC experience.

Educational System

Consider the whole of the educational system within which the MOOC might be deployed. How will the course fit with traditional ways of teaching/learning at the university? How might it affect institutional, faculty, and student thinking about the essential ingredients of a university education? How might it change the status of faculty, the security of teaching staff? How will the value of successful completion of a MOOC be judged and by whom?

MOOC lectures may be professionally prepared, with a top scholar in the field leading the cast, and this may very well be seen by faculty who are urged (or required) to adopt the MOOC in their own teaching as a deficiency and a constraint on learning. Such faculty will have their own perspective on and approach to the knowledge domain, and these may differ in important ways from those of the MOOC lecturer.

Domain knowledge and paths to knowing are not the sole property of a single scholar—there are other narratives, priorities, and approaches to the subject matter. This is more obviously characteristic of courses in the humanities, but it holds in engineering and the sciences as well. For teachers who have developed their own approach to a subject, a series of video lectures would seem a straitjacket, limiting their freedom of expression and reflection and perhaps those of their students as well.

In fact, we have seen this reaction. In 2013, the California State University system began promoting the use of MOOCs. In reaction, the philosophy faculty at San Jose State University published an open letter objecting to the university president's decision to add to the department's curriculum a MOOC led by a distinguished Harvard professor.[6]

[6] "An Open Letter to Professor Michael Sandel from the Philosophy Department at San Jose State U.," Chronicle of Higher Education, May 2, 2013; available at http://chronicle.com/article/ The-Document-an-Open-Letter/138937/.

They explained,

When a university such as ours purchases a course from an outside vendor, the faculty cannot control the design or content of the course; therefore we cannot develop and teach content that fits with our overall curriculum and is based on both our own highly developed and continuously renewed competence and our direct experience of our students' needs and abilities.

They then raised a fear others have voiced:

[S]hould one-size-fits-all vendor-designed blended courses become the norm, we fear that two classes of universities will be created: one, well-funded colleges and universities in which privileged students get their own real professor; the other, financially stressed private and public universities in which students watch a bunch of video-taped lectures and interact, if indeed any interaction is available on their home campuses, with a professor that this model of education has turned into a glorified teaching assistant.

Will MOOCs, which to date are productions of leading universities, reduce the status and value of second-tier institutions of higher learning? Will administrations promote the adoption of MOOCs and then feel they no longer need tenured faculty to teach their students? Such developments would make for a two-tiered system that would, in turn, diminish the overall quality of the institutional choices available to students. Will a growing inequality in higher education, exacerbated by MOOCs, mirror the growing economic inequality in American society?

At present, each university (and the accreditation agencies) implements quality control, while respecting academic freedom. Now consider a world where many courses are presented as MOOCs and the accreditation system proves unable to cope. When MOOCs proliferate and compete in the open market, students may be drawn to the most entertaining courses, or the easy courses, or the courses that present a position they agree with. Millions of students could receive college credit for courses of little value (e.g., they teach theories that are outdated or held in disrepute).

On the one hand are mercurial youth of university age seeking academic credit, and on the other are self-motivated, mature, older individuals who perhaps care less about certification.

Such fears may be overblown, and with time and trial MOOCs may emerge as useful and valid means of education. But in the meantime much mischief can be done in an atmosphere of hubris, optimistic promises, and inadequate information; for example:

- Research on learning is limited to questions that are answered by click data (comparable to looking for the lost keys under the lamp post because that is where the light shines).
- Certification is taken over by third parties, independent of providers, resulting in a loss of faculty control over educational content.
- Costly, unpopular programs are dismantled without consideration of costs and benefits, and staff let go for lack of enthusiasm for the MOOC (Rice 2012).

Making More of MOOCs

MOOC providers and the media proclaim a new age of enlightenment for the youth of the world. But something is amiss. A look at who registers shows that the great majority already have at least a bachelor's degree or its equivalent. And while a significant fraction are the age of university students (like the individuals in a producer's corresponding residential course) only a few of these gain certification. For example, Duke University's first MOOC, offered through Coursera, had 12,000 registrants, 11% of whom had at most a high school degree or equivalent. Ten people in this group successfully completed the course (Belanger and Thornton 2013).

MOOC providers need to recognize this twofold character of "the market." On the one hand are mercurial youth of university age seeking academic credit, and on the other are self-motivated, mature, older individuals who perhaps care less about certification.

In the discussion that follows, we define "youth" as students, regardless of age, who undertake study online in pursuit of a degree. The UPenn study showed that 13.2% of the 34,779 students surveyed enrolled to "gain knowledge to get my degree" (Christensen et al. 2013). We define "mature" registrants as all others, the great majority of whom already have a bachelor's degree.

We divide mature individuals into two groups according to their interests. The first join a MOOC because it will enhance their skills on the job or help them to obtain a new job. Christensen and colleagues (2013) reported that roughly 60% of those surveyed said they enrolled to "gain specific skills to do my job better" or "gain specific skills to get a new job." These students may or may not strive to complete all the course requirements for certification.

Those in the second group register out of curiosity or learning for learning's sake. The UPenn study showed that

50%[7] of the students surveyed had enrolled out of curiosity. For these individuals, certification is not a priority.

Our recommendations, accordingly, address what needs to be done to accommodate the appetites of the mature learner and what needs to be done to provide effective online learning to meet the needs of youth.

MOOCs for the Mature

For mature individuals who participate in a MOOC to enhance their skills on the job or help in obtaining a new job and who do not seek certification, the ideal MOOC may work fine as is. And for those who register simply out of curiosity or to learn for learning's sake, the ideal MOOC needs little tinkering.

The providers themselves need to relax and stop treating the mature viewer as if he or she were sitting in the front row of their residential class. Let these registrants participate to whatever extent accords with their interests—watch the videos selectively, peruse the posted texts on occasion, do the exercises when their interest is piqued, and participate in the discussion forum or not.

Think of the "MOOC for the Mature" as akin to a TV series, with a single character providing the narrative and with some expectation that the viewer will participate in the exercises as the course rolls along week by week—a digital production valued for the "edutainment" it provides. For the 80-year-old former English teacher the MOOC works in just this way, and that is worth something.

MOOCs for Youth

The main business of universities is to educate youth. For this, the passive viewing of even an enlightening digital production will not suffice.

First, the ideal MOOC won't work for youth because university education requires more than information transfer, no matter how professionally structured. For aspiring, overtested youth, there has to be a teacher to respond to their questions, to look over their shoulder, to lead them at times, to redirect them at other times. And the teacher or professor has to know not only the subject matter through and through but also how to make effective use of the MOOC resource.

Second, if one expects university faculty outside the production process to adopt and adapt the MOOC to their perspective and approach to the course material, then more openness is required. The platform should enable, if not encourage, the disassembling and rework ing of the MOOC to fit the needs of faculty and students elsewhere.

The rhetoric will have to shift from promoting the MOOC as a professionally packaged, finished product to a collection of well thought out bits of content and a flexible, adaptable technology for engaging this content online by varied populations of faculty and students.

What's It Worth Then?

MOOC providers should accept that, for mature course registrants, the worth of their well-done productions depends on the individual's motivation and interest.

For youth, providers need to recognize that improving university-level education will take more than the development and posting of an ideal MOOC. It requires the recognition that knowledge as information, no matter how artfully, dramatically, convincingly portrayed online, is not the driver in the education of youth. What matters is what the students themselves bring to the show, how they engage the material, under the guidance of an experienced teacher.

The talking head may enlighten, the multiplayer game may engage, but if students are to learn they must be challenged to reflect and apply what they see and hear to situations less well defined, more open, and even ambiguous. For this teachers with their own narrative and perspective are essential, to encourage critical thinking and reflection, and to set a coherent path through the subject matter.

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[7] The percentages add to more than 100 because multiple selections were allowed.

International News

International Union for the Conservation of Nature

CITES and IUCN bolster collaboration in tackling poaching and illegal wildlife trade

The Secretariat of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and IUCN have signed an agreement in August 2015 to strengthen the cooperation between the two organizations in minimizing the illegal killing of and related illegal trade in elephants and other CITES-listed flagship species in Sub-Saharan Africa, the Caribbean and the Pacific region.

The agreement has been signed in the context of the project known as MIKES (Minimizing the Illegal Killing of Elephants and other Endangered Species), funded by the European Union.

Over recent years, there has been a surge in illegal wildlife trade, with elephants, rhinos, pangolins and some precious timber species among the most heavily affected. The illegal trade in these species is global in nature and is taking place at an industrial scale. Over 100,000 elephants are estimated to have been poached for their ivory from 2011 to 2013 across the African continent. In 2014, 1,215 rhinos were killed for their horns in South Africa alone—a figure that has risen alarmingly since 2007 when just 13 rhinos were poached.

In combatting illegal wildlife trade, States are increasingly being confronted by transnational organized criminals, and in some cases rebel militia and rogue elements of the military, which have been driving poaching and illegal trade destined for illicit markets. The same illegal infrastructure is used for the illegal trafficking in drugs, weapons and humans.

Wildlife crime continues to be a major problem worldwide, estimated by some to be worth up to 20 billion U.S. dollars a year. This ranks it among some of the most serious transnational crimes, including people and arms trafficking.

The new agreement will build upon the active participation of elephant range States in the CITES Monitoring the Illegal Killing of Elephants (MIKE) program over the past 15 years, but with an enhanced focus to include other CITES-listed flagship species threatened by illegal trade, and extending operations to the Caribbean and Pacific regions.

Fore more information, visit https://www.iucn.org/news_homepage/?21814/CITES-and-IUCN-bolster-collaboration-in-tackling-poaching--and-illegal-wildlife-trade.

World Resources Institute

New Global Data Finds Tropical Forests Declining in Overlooked Hotspots

The world lost more than 18 million hectares of tree cover in 2014, an area twice the size of Portugal, according to new data from the University of Maryland (UMD) and Google released by Global Forest Watch. The data find that tropical forests are in the most trouble, losing 9.9 million hectares of tree cover in 2014—over half of the global total. A three-year-average shows tree cover loss is the highest it's been since 2001.

The data identify new hotspots emerging in the Mekong River Basin, West Africa, South America's Gran Chaco region and Madagascar. The 2014 data confirm that countries with the fastest acceleration of tree cover loss are (starting with the highest): Cambodia, Sierra Leone, Madagascar, Uruguay, Paraguay, Liberia, Guinea, Guinea-Bissau, Vietnam and Malaysia. Globally, increasing demand for rubber and palm oil, expansion of soy farming and cattle ranching, and expansion of other agricultural commodities are driving deforestation in unexpected places.

The new data show that tree cover loss is rapidly accelerating in the tropics, home to some of the world's most biodiverse and carbon-rich forests. And, much of the clearing is taking place outside typical hotspots Brazil and Indonesia. More than 62% of forest loss occurred in countries outside of Brazil and Indonesia in 2014, compared to 47% in 2001.

UMD and Google's new data measures tree cover loss, using satellites to see all types of clearing and death of trees for all types of tree cover, from tropical rainforests to boreal forests and plantations at high resolution. The new data was made possible through free public access to satellite imagery provided by the U.S. Geological Survey Landsat program, in partnership with NASA.

The new tree cover data is one way of using technology to gain transparency into the world's environment and development challenges. The new data represent the largest and most up-to-date global data set for tree cover loss. Global Forest Watch now features annual tree cover loss data spanning 2000-2014 at 30-meter resolution.

The 2014 forest data is publicly available through maps, data visualizations, and downloads at globalforestwatch.org.

For more information, visit http://www.wri.org/news/2015/09/release-new-global-data-finds-tropical-forests-declining-overlooked-hotspots.

Meetings

See http://www.rnrf.org for additional meetings

Submit Meeting Notices to: info@rnrf.org

November 2015

Geological Society of America Annual Meeting. November 1-4, 2015. Baltimore, MD. http://www.geosociety.org/meetings/2015/

SETAC North America Annual Meeting: Cross-Pollination for Environmental Progress. November 1-5, 2015. Salt Lake City, UT. http://slc.setac.org/

Natural Areas Conference. November 3-5, 2015. Little Rock, AR. http://www.naturalareasconference.org/

Society of American Foresters National Convention. November 3-7, 2015. Baton Rouge, LA. http://www.xcdsystem.com/saf/site14/

American Society of Landscape Architects Annual Meeting. November 6-9, 2015. Chicago, IL. http://www.asla.org/annualmeetingandexpo.aspx

Climate Central and the Association of Climate Change Officers Rising Seas Summit. November 12-13, 2015. Cambridge, MA. http://www.risingseassummit.org/

American Society of Agronomy, Crop Science Society of America, Soil Science Society of America Annual Meeting. **Synergy in Science: Partnering for Solutions**. November 15-18, 2015. Minneapolis, MN. https://www.acsmeetings.org/

American Water Resources Association, 2015 Annual Water Resources Conference. November 16-19. Denver, CO. http://www.awra.org/meetings/Denver2015/

Association of Outdoor Recreation and Education Conference: Engineered for Adventure. November 18-20, 2015. Atlanta, GA. http://www.aore.org/conference

UN Climate Change Conference, UNFCCC COP 21/CMP 11. November 30-December 11, 2015. Paris, France. http://unfccc.int/meetings/unfccc_calendar/items/2655.php?year=2015

December 2015

RNRF Congress on Sustaining Western Water. December 1-2, 2015. Washington, DC. http://www.rnrf.org/2015cong

Nutrient Management & Edge of Field Monitoring Conference. December 1-3, 2015. Memphis, TN. http://www.swcs.org/en/conferences/specialty_conferences/nutrient_management_and_edge_of_field_monitoring/

International Water and Climate Forum. December 7-9, 2015. San Diego, CA. http://www.waterclimateforum.org/

American Geophysical Union Fall Meeting. December 14-18, 2015. San Francisco, CA. http://fallmeeting.agu.org/2015/

Groundwater Expo. December 15-17, 2015. Las Vegas, NV. http://groundwaterexpo.com/

January 2016

EWRI/ASCE 8th International Perspective on Water Resources and the Environment. January 4-6, 2015. Colombo, Sri Lanka. http://ipweconference.org/

American Meteorological Society Annual Meeting. January 10-14, 2016. https://annual.ametsoc.org/2016

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