RENEWABLE RESOURCES JOURNAL

VOLUME 34 NUMBER 4

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Youth Mobilization to Stop Global Climate Change: Narratives and Impact

Heejin Han and Sang Wuk Ahn

Galvanized by Greta Thunberg's idea for Friday school strikes, "climate strikes" emerged in 2018 and 2019 as a form of youth social movement demanding far-reaching action on climate change. Youths have taken various actions to combat climate change, but academics have not paid sufficient attention to youth climate mobilization. This study thus examines the questions of what has motivated youth to mobilize and how they have shaped global climate politics and governance. This study focuses particularly on the narrative of youth activists to address their understanding of climate change and their ideas regarding how to respond to it. Youth collective action has succeeded in problematizing global climate inaction and inertia and in framing climate change from a justice perspective, but activists have faced limitations in converting their moral legitimacy into the power required for sweeping changes. Overall, this study demonstrates the emergence of young people as agents of change in the global climate change arena and the urgency of engaging them in climate change governance and policymaking.

Introduction

Climate change is one of the most urgent issues confronting the international community. To address global climate change and its far-reaching impacts, governmental, intergovernmental,

and nonstate actors have targeted multiple fronts on different scales. In particular, over the years, various nonstate actors, including nongovernmental organizations (NGOs), citizens, and the private sector, have complemented governmental and intergovernmental efforts, combining their unique strengths and resources in combatting climate change both locally and transnationally.[1,2]

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The international community recognized the importance of engaging various societal groups in environmental policymaking early on. During the U.N. Conference on Environment and Development (known as the Earth Summit) in 1992 and in the subsequent Agenda 21, nine major groups were designated as channels for achieving the world's sustainable development goals. Those groups included women, children and youth, indigenous peoples, farmers, business and industry, labor and trade unions, science and technology, local authorities, and NGOs. Existing studies have discussed their engagement with and participation in climate activism [3–9]. However, few academic analyses have addressed the mobilization of youth in global climate politics (the definition of youth differs, but this paper uses ages 15–24 to mean youth, a definition based on the U.N.'s World Youth Report published by the Department of Economic and Social Affairs[10], according to which there are 1.2 billion young people, accounting for 16% of the global population).

Young people are related to climate change in multiple ways. On one hand, their experiences with climate change are negative and pessimistic. Young people will live much of their lives on Earth whose conditions are increasingly altered by climate change. Various dimensions of their lives, including their security, well-being, and even mental health, will be negatively affected by climate change[11]. Recent studies have shown how climate change and extreme weather events have negatively affected the physical and mental health conditions of young people, including children[12–14]. Climate change also affects the socioeconomic conditions in which youth live. For instance, in developing regions such as Africa, young people, which constitute the largest demographic group and the largest labor force in terms of the agricultural sector, are exposed to growing existential threats, as climate change has altered environmental conditions such as water availability. Moreover, a changing environment often engenders conflict

between various youth groups over the use of scarce resources[15].

On the other hand, on a more positive note, youth can be seen as environmental stewards for the future. For instance, teenagers have fought against climate change through various forms of activism, including lawsuits against fossil fuel companies and governments[16]. In the case *Juliana v. U.S.,* 21 teenagers from Oregon filed a constitutional lawsuit against the federal government and the fossil fuel industry in August 2015, arguing that their government had failed to address climate change, violating their rights to life, liberty, and property, and had failed to protect essential resources in the public trust[17]. Similar lawsuits have been litigated in developing countries, including Colombia and Pakistan[16]. Moreover, young people in some developing countries have spearheaded efforts to confront climate change and its adverse consequences[15], prompting international institutions such as the U.N. Development Program[18] to finance various youth-led environmental projects around the world.

Renewable Resources Journal

Renewable Resources Journal (ISSN 2578-3998) is published quarterly by the Renewable Natural Resources Foundation, 6010 Executive Boulevard, Suite 700, North Bethesda, MD 20852-3809, USA. Tel: +1 301 770 9101 Email: info@rnrf.org Website: https://www.rnrf.org

Editorial Staff: Robert D. Day, editor; Madeline Voitier, assistant editor; Stephen Yaeger, assistant editor.

Despite such actions, young people are still portrayed as disengaged from civil action[19]. One study[20] argued that GenX'ers (born 1962–1981) and Millennials (born after 1982) prioritize extrinsic values such as money and fame over intrinsic values such as community and and affiliation. The study found declining patterns in these generations in terms of civic orientation, e.g., political participation and interest in social problems, with the largest decline being observed in the "environmental action" category.

This depiction, however, has been shattered by the youth climate movement that swept the world in the years 2018 and 2019, which became one of the most widespread environmental social movements in history. School strikes for climate have been associated with Greta Thunberg (hereafter, Thunberg), whose Friday school boycotts grabbed international attention. This Swedish teenager used strikes to demand the adoption of more aggressive climate policies on the part of older generations, governments, and international organizations. She has since inspired other teenagers, leading millions of them to join her by taking to the streets. Although they are scattered all over the world, the movement participants have demanded drastic actions such as an immediate reduction in greenhouse gas emissions and a fossil fuel phase-out.

Youth participation in politics is not new, as they have played various roles in domestic and international politics, triggering political and socioeconomic transformations such as democratization. Young people have played

significant roles in various movements, e.g., the U.S. civil rights, feminism, environmentalism, antiwar, labor, and immigrant rights movements[19,21]. Examples vary, from the 15 April – 4 June 1989 Tiananmen Square Protests to the Arab Spring. What is relatively new, however, is that young people have emerged as agents of change in a social movement aimed at stopping the global climate crisis at an unprecedented scale. They have adopted the language of justice to make climate change a salient issue and to reveal the failure and inaction of the existing establishment, including political leaders and fossil fuel companies. While one cannot measure the direct causal impact that these climate strikes have had on state and intergovernmental climate change policies, this worldwide youth mobilization has aroused a sense of urgency, provided an alternative discourse, and cultivated youth leadership and commitment to civic action[22].

Youth Climate Movement

In 1992, a 12-year-old Canadian girl named Severn Cullis-Suzuki, the founder of the Environmental Children's Organization, spoke at the Earth Summit. In her six-minute speech, Cullis-Suzuki[24] explained what drove her to speak up about the environment:

> *We felt it was important to go. We figured it was going to be mostly old men, sitting around, making decisions that are going to affect our future and the future generation. So we wanted to go as the conscience, as a reminder to those decision-makers, who their decisions would truly affect.*

A similar message was delivered by a Swedish teenager in 2018, but with far greater impact. In her "School Strike for Climate", which was launched in late August 2015 in front of the Swedish parliament, Greta Thunberg vowed to continue her protest until her government met the carbon emissions target set out in the Paris Agreement[25]. Utilizing social media outlets such as Instagram, Twitter, Facebook, and YouTube—tools not available to Cullis-Suzuki and her peers—Thunberg and her social-media-savvy peers began sharing hashtags, such as #FridaysForFuture (FFF) and #Climatestrike, with people across the world. Attracting media attention, Thunberg was soon invited to talk at high-profile events: in November 2018, she delivered a TED talk, and in December, she delivered a speech at the U.N. climate change conference, COP24, in Poland. In the meantime, Thunberg's actions snowballed into a larger youth mobilization. In December, about 20,000 students from 270 European cities and towns held school strikes[25].

Youth activism continued throughout 2019. By the end of 2018, tens of thousands of students across Europe had joined school strikes. In January, the number reached 35,000 in Belgium alone. When a Belgian environmental minister insulted the strikers, a public outcry forced her to resign[26]. On 15 March 2019, 1.4 million people in over 1,700 cities[27] worldwide participated in strikes to raise public awareness regarding governments' inaction on climate change and to call for policies that would comply with the Paris Agreement. Another estimate was that about 1.6 million students in over 120 countries participated in the strikes[28]. According to FFF's website, 359 events had registered a week before the strike, but by the day of the global strike, about 2,700 events had registered. Although the number of participants and events cannot be exactly calculated given the amorphous nature of the movement, these numbers suggest that the scope of youth climate mobilization accelerated at an unprecedented scale.

Responding to this surge, U.N. Headquarters hosted its first Youth Climate Summit on 21 September 2019. More than 500 climate champions aged between 18 and 30 from more than 140 countries and territories were invited. Among them, one hundred were chosen as Green Ticket winners, receiving support to participate in the summit via carbon-neutral travel to New York. At the summit, the young climate champions explored ways to meet the commitments in the Paris Agreement and demanded that world leaders tackle the climate crisis with far swifter action[29]. The youth summit offered a platform for young climate activists to discuss their ideas with their peers and world leaders.

Thunberg arrived in the U.S. in late August to attend the summit on a solar-powered sailboat. She protested in front of the U.N. together with members of FFF and marched in front of the White House. She also testified in a joint congressional hearing on climate crisis and made a speech at the U.N. Climate Action Summit on 23 September. On 20 September, before the scheduled summits for both youth and world leaders, Thunberg and

millions of young people around the world (at least 117 countries) took to the streets again, criticizing the inaction of world leaders and demanding an immediate reduction in carbon emissions. According to one study[26], four million people of all ages showed up to protest around the world that day.

In addition to protests, youth activists have launched campaigns to push policymakers through more formal channels. While participating in the U.N. Youth Climate Summit, Thunberg and 14 children (from Argentina, the Marshall Islands, France, Germany, and the U.S.) lodged a formal complaint under the U.N. Convention on the Rights of the Child. They claimed that countries' failures to address the climate crisis violated the convention[30]. In Europe, youth activists utilized the European Citizens' Initiative (ECI) as an outlet to pressure the E.U. Parliament. The ECI enables E.U. citizens to call on the European Commission (EC) to enact concrete demands or to propose a legal act. FFF aimed to collect one million signatures, enough to pressure the E.U. Parliament into prioritizing the climate crisis and introducing drastic measures. FFF formed an ECI team in April 2019, which soon grew to around 150 activists. They composed drafts and sent them to national FFF teams for feedback. The final draft was submitted in July to the EC, which opened for signature collection on 23 September[31]. This campaign was intended to pressure the EC into responding to the climate emergency. More specifically, the activists demanded the following: (1) that the E.U. adjust its goals under the Paris Agreement to an 80% reduction of greenhouse gas emissions by 2030 (to reach net zero by 2035), and that European climate legislation be adjusted accordingly; (2) that an E.U. Border Carbon Adjustment be implemented; (3) that no free trade treaty be signed with partner countries that did not follow a 1.5 C compatible pathway (according to Climate Action Tracker); and (4) that the EU create free educational materials for all members about the effects of climate change.

The above was just a brief description of the climate movements that unfolded from 2018 and throughout 2019. While such youth environment movements were not entirely new, such global-scale youth mobilization on environmental issues was unprecedented.

Achievements and Limitations

Discussing, and even trying to measure the impact of, social movements is an elusive task. The efficacy of various social movements, including protests to leverage change and force climate change action onto the mainstream agenda, remains to be seen[34,35]. Therefore, this section examines the short-term responses that the youth climate mobilization seems to have elicited in the biographical, social, and political domains and discusses its limitations.

First, in the biographical domain, the 2018–2019 youth climate movements succeeded in enlisting the support of young people around the world by using powerful and persuasive narratives that unite them. Not just youth but people around the world began to pay closer attention to climate change issues as the mobilization of young people in school strikes, street protests, and online activism reached an unprecedented level in 2018 and 2019. According to Meltwater, a media monitoring firm[36], there were more than 7.5 million social media mentions of Thunberg as an icon of the youth movement from 20 September 2019 to 26 September 2019, while news outlets around the world mentioned her 93,800 times. Meltwater also estimated that more than 3.58 million social mentions were made regarding the global climate strike before the U.N. Climate Action Summit on 20 September. The majority of these mentions were aimed at generating climate awareness and urging people to join movements to pressure policymakers.

Mainly due to youth activism, the term "climate strike" was named the Collins Dictionary's 2019 word of the year, due to a 100-fold increase in the use of the word. The dictionary defined it as a "form of protest in which people absent themselves from education or work in order to join demonstrations demanding action to counter climate change"[37]. The term first arose in 2015 during the U.N. climate change conference in Paris, but then was not widely used until late 2018, when the climate school strikes gained momentum and millions of people joined global climate strikes (during the "Global Week for Future")[37]. Likewise, the Oxford Dictionary declared "climate emergency" the word of the year for 2019, defining the concept as "a situation in which urgent action is required to reduce or halt climate change and avoid potentially irreversible environmental damage resulting

from it"[38]. These climate-related expressions gained global recognition in 2019 mainly due to global youth mobilization.

Secondly, in the social domain, the youth climate movements enlisted broader constituent groups, including labor workers, teachers, and existing environmental groups, as collaborating partners, forming networks to stop climate change. For instance, in the United States, where thousands of students launched school strikes to participate in the Global Week for Future, the American Federation of Teachers joined them in navigating polices regarding student absences and in organizing logistical support. The federation also endorsed climate strikes[39]. Demonstrations in Washington, D.C., indicated the wide array of organizations supporting the movement. Led by D.C. public school students, the Washington Teachers' Union, the Sunrise Movement, Zero Hour, OneMillionOfUs, 350.org, D.C. Youth Climate Strike, the National Children's Campaign, Our Children's Trust, and others marched to the Capitol with a message for legislators: Act now to save the planet[39].

Education International[40], which is composed of 30 million members from 401 organizations from 172 countries, also announced its endorsement of the students' actions as follows:

> *The action of students on climate change has not only forced discussions in many countries about the issue, but has also revealed the weak response of many democracies to the most compelling needs of the population and the planet. This mobilization can contribute to and help inspire a process of reinvigoration of the democratic process.*
>
> *Education unions stand with the students. We urge governments to make the necessary structural changes for a just transition towards a climate-resilient and low-carbon economy. Climate change is not combatted through the "good behavior" of consumers. Coordinated and sustained participation of students and workers and their representatives may be the first step towards climate justice. We stand by students in the demand for urgent climate action, and a just economic transition.*

Numerous existing environmental organizations that engage in climate-related activism, e.g., divestment movements, have acknowledged the significance of this youth mobilization. For instance, Sini Harkki, the program manager of Greenpeace Nordic, stated that it really has "changed the discourse"[28]. These suggest that the youth mobilization has triggered some positive change in the social domain.

The youth strikes also succeeded in enlisting the support of labor unions. Trade unions across the world showed interest in organizing strikes in conjunction with the youth climate strikes. For instance, in Germany, the second largest labor union asked its two million members to join the #climatestrike in September 2019. In the U.S., 900 Amazon workers based in Seattle participated in the strike on 21 September. The support that young people elicited from the labor groups demonstrated successful green–blue alliances.

Third, in the political realm, the 2018–2019 youth-led climate movements seem to have influenced climate change policies in some countries or elicited a commitment to do more. After Thunberg spoke to Parliament and demonstrated with Extinction Rebellion, a British environmental group, the U.K. government passed a law requiring the country to eliminate its carbon footprint[26]. Moreover, although the U.N. Climate Action Summit was marked by the absence of several big players, such as the U.S. and Brazil, some state leaders promised a fossil fuel phase-out. Angela Merkel, the German chancellor, declared that coal mining would end in Germany by 2038. Emmanuel Macron, the French President, called for the E.U. to accelerate its emissions reductions, promising that France would not make trade deals with countries who had not endorsed the Paris Agreement. In discussing his government's plan, Macron was quoted as saying, "We cannot allow our youth to strike every Friday without action," in reference to the climate school strikes[30].

Moreover, several governments (10 countries, including Sweden, Chile, and Spain) signed the Declaration on Children, Youth, and Climate Action[41] on 9 December 2019 during COP25 in Madrid. The declaration acknowledged the critical roles of children and youth as agents of change and contained a commitment to taking action on several youth-related climate goals: the promotion of youth rights, including a right to a healthy environment; investment in youth capacity, including mitigation and adaptation actions; and the promotion of

youth participation in climate governance. Given the timing of this declaration, one can infer the influence that the preceding global youth mobilization had on it.

At the global governance level, the youth climate movements demonstrated the significance of young people as agents of change and shattered existing stereotypes about young people being mere victims of climate change or lacking an interest in the issues affecting them. The 2018–2019 movement demonstrated that young people actively process scientific information regarding climate change, condense this information by generating narratives, communicate the narratives, and use them as tools in collective action settings, such as climate strikes. The sheer scale and size of the movement reminded world leaders of the necessity to bring youth to the table. This led to the U.N.'s first ever youth climate summit, which took place prior to the U.N. Climate Action Summit. More than 500 young people from 60 countries were invited to talk at this event. The summit was a gesture granting young people space and visibility in a formal international setting.

At the U.N. Youth Climate Summit, U.N. Secretary General António Guterres stated he saw a change in momentum in movements such as those spearheaded by Thunberg and other grassroots initiatives. He encouraged young participants to continue fixing his generation's failures and to make the latter accountable for preserving justice in the world and for the planet[33]. The deputy secretary general also said that never before in history had the U.N. offered such a visible platform to young people at a political summit, stressing that this was a testament to the fact that they were a leading force for climate action and were drawing worldwide attention to the climate emergency in a way that had been impossible to imagine previously[32].

While the global youth mobilization to stop climate change generated the aforementioned responses, there were several limitations as well. The youth activists successfully problematized the unequal distribution of power and resources underlying the current climate crisis. However, the movement was limited in its ability to alter such a system in favor of those who support more progressive climate policies. Those supporting the status quo continue to consolidate their power and interests by mobilizing resources and by controlling money, political power, and public discourse. Those groups have not simply surrendered to good morals and scientific arguments[23]. Youth climate activists do not have much leverage against governments and fossil fuel companies that resist change.

For instance, Dolsak and Prakash[42] agreed that climate strikes raise the policy profile of climate change and give agency and hope to younger generations. Moreover, climate strikes provide an excellent opportunity to inculcate a climate ethic among strikers, so that they begin to embody the change they are demanding from others. However, they argued that youth climate movements are unlikely to impose huge costs on firms or policymakers and will accomplish more by focusing on persuading constituencies to enact climate change policies and by demanding climate leadership from universities.

Second, while the climate strikes have succeeded in gaining global attention (for instance, the U.N. setting up an official space for youth participants), this space remains very limited[43]. Powerful international organizations and member states are the ones with the power and authority to grant such space. About 1,024 young people showed up to the Youth Climate Summit, but only a handful of these activists were given the opportunity to address the Climate Action Summit that followed. The youth summit allocated only several hours for youth participants from all over the world to discuss climate change issues and share ideas. The activists themselves felt there was nothing productive and tangible that came out of this symbolic event[44]. This means that international institutions such as UNEP[45] and UNFCCC and the institutional context can affect the activists' ability to shape climate change policy[46,47].

Third, while the youth activists generated powerful narratives calling for immediate action, they fell short of offering concrete solutions. Rather, the youth activists urged older generations, whom they identified as villains in their narratives, to come up with drastic action plans. Moreover, many of the ideas proposed by the youth participants at the Youth Climate Summit were local suggestions that were limited in terms of their relevancy to a global problem such as climate change. Therefore, though Thunberg and the youth activists received credit, they were also dismissed as climate alarmists, causing people to fear the apocalypse[48]. The world leaders of the

countries with the highest levels of emissions, for instance, simply dismissed the youth climate activists, including Thunberg. Vladimir Putin disparaged Thunberg and youth climate activism by saying "I don't share the common excitement" on a panel in October. Donald Trump sarcastically described Thunberg as "a very happy young girl looking forward to a bright and wonderful future" on Twitter in the week preceding the U.N. Climate Action Summit. After Thunberg tweeted about the murder of indigenous people in Brazil, the country's president, Jair Bolsonaro, called her a "little brat"[26]. Although Thunberg was nominated for the Nobel Peace Prize in 2019, and Thunberg and the FFF movement were honored with Amnesty International's Ambassador of Conscience Award in 2019, these youth activist groups have also been simply brushed aside as immature.

Conclusions

The 2018–2019 youth movement around climate change was unprecedented in terms of its scale, although young people have led various forms of social movements throughout history (e.g., teenagers mobilizing against gun violence in the United States and students fighting for democratic representation in Hong Kong)[26].

This youth movement succeeded in raising the profile of climate change as a pressing global issue of the highest priority, enlisting broad societal endorsement and prompting incremental policy changes on the parts of some states. This youth activism also reminded the world and international organizations such as the U.N. of the need to incorporate the voices of youth into global climate governance. Moreover, youth climate mobilization created a global attitude shift, elevating the importance of climate change in the global agenda and calling for urgent social transformation[26]. However, the youth climate movement and its participants lacked the power to bring about immediate policy changes. While they portrayed themselves as heroes in their narrative, they were limited in translating their moral authority and legitimacy into power and in offering powerful policy alternatives to the status quo.

Despite this mixed impact, the youth climate movement demonstrated that young people support their peers and other social groups to promote common goals and values and to bring about the social change they desire [68,106]. This youth mobilization demonstrated the possibilities for leadership and agency among young people at a time when powerful and resourceful governments have backed away from climate change commitments [68]. This story of activism contrasts sharply with some existing descriptions of young people, which depict them as fragile and helpless victims of climate-induced disaster and physical and psychological distress. Some studies have also portrayed them as a passive and self-centric political group that is not interested in forming networks with others or in resolving environmental issues such as climate change. These youth-led climate movements defied these stereotypes.

This new image of young people as agents of change and as active architects of future climate policymaking suggests the urgency of recognizing them as competent citizens and meaningfully engaging them in deliberative processes[27,50-52]. Currently, young people and youth organizations are formally represented by YOUNGO as an official constituency of the UNFCCC. However, a recent study shows how youth participants from YOUNGO are hindered by the exercise of power by other stakeholders, which prevents the former from articulating their preferred claims[43]. Moreover, such an outlet is limited to authorized youth organizations and their members. Given the rising global youth activism and its impact as demonstrated in this study, it is necessary to create multiple formal and informal venues for dialogues with young people so that their interests and ideas are incorporated into global climate governance.

"Youth Mobilization to Stop Global Climate Change: Narratives and Impact" was originally published in the journal *Sustainability*. This article consists of adapted selections from the original, which is available here.

Youth Climate Organizations

The rise of the youth climate movement described in this article has been led by several new youth-oriented climate organizations. Frequently in collaboration with one another, these groups have used a diverse set of approaches to promote meaningful action on climate change. Editors have prepared a list of many of these organizations and a description of their role in the movement.

Defend Our Future is a youth organization founded by the Environmental Defense Fund to empower young people interested in advancing climate change and clean energy solutions.
Its platform emphasizes bipartisanship on climate solutions to create a clean energy economy and ensure clean air and water for all.

Divest Ed is an organization that supports student-led campaigns demanding that their universities divest from the fossil fuel industry. They provide mentorship, leadership development, connections to other campus divestment organizations, and help with successful organizing.

Earth Uprising is a youth-led organization founded in 2017, working through local youth groups and university chapters to support climate action and education. They hold events and protests, lobby local governments, and advocate for including climate change-focused material in the curriculums of primary schools, high schools, and universities.

Fridays for Future is the global climate protest movement started by Greta Thunberg, encouraging young people around the world to join climate strikes every Friday. Perhaps the most high-profile face of the youth climate movement, it has expanded across all continents, 7,500 cities, and over 13 million people have participated in it.

The International Indigenous Youth Council was founded during the 2016 protests against the construction of the Dakota Access Pipeline on the Standing Rock Sioux Reservation. They focus on community organizing and non-violent direct action to build youth leadership in protecting water, land, and treaty rights, as well as promoting indigenous culture and social justice.

OneMillionOfUs is a youth-led international activist group founded in 2019 to rally young people to register to vote in the 2020 presidential election and beyond. The climate crisis is only one of their priorities; they also focus on other issues important to young people, such as immigration reform, racial and gender equality, and ending gun violence.

Sunrise Movement is a youth-led organization founded in 2017 to support pro-renewable energy candidates in the 2018 midterm elections. Since then, they have expanded their focus to support the Green New Deal, a proposed package of legislation that would address climate change and economic inequality.

Schools for Climate Action is a non-partisan campaign to empower schools to speak up about climate action. They support school boards, student councils, school environmental clubs, PTAs, teachers' unions, and school support organizations to promote the recognition of climate change as a generational justice issue, support common-sense climate policies, and expand school district responses to climate change.

U.S. Youth Climate Strike, as their name implies, organizes and supports climate strikes and protests across the U.S. Their list of demands goes past just a transition toward a net-zero economy, including demands for support for those with disabilities, indigenous rights, housing rights, and biodiversity protections, among other issues.

Zero Hour was founded in 2017 to promote the voices of young people in the conversation around climate change. They started by organizing the Youth Climate March on the National Mall in July of 2018, and have continued since then organizing other demonstrations and events to elevate youth voices on climate change. Most recently, they have partnered with the **National Children's Campaign** to start the #Vote4OurFuture campaign, aimed at galvanizing the American people to vote in the interests of the nation's youth.

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How Development of America's Water Infrastructure Has Lurched Through History

David Sedlak

Throughout history as cities grew, new water infrastructure was built to supply this vital resource to increasing numbers of people. Initially, urban dwellers carried water from hand-dug wells and lakes and streams that ran through the city. As cities advanced, engineers built aqueducts and canals to import water from great distances. Among the engineering marvels of the ancient world, the Roman water system of elevated aqueducts, underground piping, and the world's first sewer network is an iconic example of the ingenuity that made possible Europe's first city of a million people.

Modern water systems owe a lot to the Roman innovations from 2,000 years ago. But instead of celebrating the technology that has allowed millions of people to survive in places where the local water supply is limited, we hide our water infrastructure underground and go about our daily lives oblivious to these lifelines. Today, we talk about urban water systems only when they fail. And therein lies our current problem: Much of the water infrastructure in the United States, Western Europe, and many other places is aging and in serious need of replacement or upgrading, especially to address the effects of a changing climate and new generation of man-made contaminants.

Due to our complacency, only a serious crisis that could leave people without access to tap water is likely to free up the financial resources needed to bring water infrastructure—which in many places still includes pipes from the 1800s—into the 21st century. Absent an emergency, cash-strapped water utility managers will continue to deal with aging water systems by economizing on routine maintenance and deferring upgrades for as long as possible. This chronic funding shortage is so dire that the American Society of Civil Engineers has awarded the drinking water infrastructure of the United States grades of D-minus or D for over a decade.

Our reluctance to invest means that we allow our water systems to deteriorate until they nearly fail and invest in them only after the public decides that the status quo is unacceptable. Our water systems' shortcomings were brought to the public's attention by Flint, Michigan's, recent experience. But it doesn't end there: Water systems are teetering on the edge of viability in numerous cities. We have seen this pattern before—and the present-day warning for us all is that the past is often prologue.

As the United States grew during the 1800s, it transformed from an agrarian nation to an industrialized one as populations increased and built drinking water infrastructure on a grand scale. But these developments had less to do with real planning than with reacting to crises. The first crisis occurred when the rapid population growth overwhelmed the water infrastructure of the period—typically shallow wells or small reservoirs located within the city—leaving it unable to provide sufficient quantities of drinking water.

The clearest example of this was in New York, where the population more than tripled, from about 60,000 people to more than 200,000 people, between 1800 and 1830. After decades of denial by city leaders during which the wealthy drank water provided by the Manhattan Water Co. (the predecessor of Chase Bank) while the poor drank well water of dubious quality, New York's leaders invested $9 million (about $850

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This article was originally published in Trend Magazine, *a publication of the Pew Charitable Trusts.*

per person in today's dollars) to import water to the city using a system of canals, pipes, and reservoirs situated about 40 miles to the north.

Building upon this early success, New Yorkers spent another $177 million (about $500 per person today) to expand their water system out another 60 miles in search of more clean water as the city grew in the subsequent decades. This pattern of population growth outstripping the capacity of local water supplies, followed by investments of hundreds of dollars per person to import water from great distances, also took place in Boston, Washington, Philadelphia, and other cities during this period. The periodic crises of growing East Coast cities taught the young country some valuable lessons. The technological know-how gained from the construction of dams and reservoirs helped our nation's westward migration that began several decades later when leaders of Seattle, San Francisco, and Los Angeles were able to build massive imported water systems before their cities reached a state of crisis.

These solutions to the nation's first water crisis, though, spawned its second one. Once city dwellers had access to large quantities of water, per capita water consumption increased as they indulged in stay-at-home baths and replaced their outhouses with indoor toilets. The sewage produced by city dwellers flowed to the nearest rivers, which often served as the drinking water supply for the next downstream city. By the late 19th century, typhoid fever and other waterborne diseases had increased to epidemic levels.

The new challenge was to develop treatment plants that could make sewage-contaminated waters safe to drink. By the early 1900s, billions of dollars had been invested in the new technology of drinking water treatment. The corresponding decrease in waterborne disease and lengthened life spans resulting from these advances has been hailed as one of the top five technological achievements of the 20th century by the National Academy of Sciences. Thanks to water filtration and chlorination, the second water crisis was averted.

America's third water crisis occurred as cities again grew during the economic expansion that followed World War II. As people migrated to urban areas, the increased volume of wastewater they produced overwhelmed the assimilative capacity of the nation's rivers, lakes, and estuaries, which had purified the modest amount of pollution that they had received in the previous years. For the next 25 years, foul smells emanated from urban waterways, dead fish washed up on shorelines, and runaway algal blooms became the norm in lakes. Water pollution was a nuisance, but city leaders lacked the will to tax their constituents to build sewage treatment infrastructure that might benefit downstream communities more than their own—and the state of the nation's waterways further deteriorated until the early 1970s. It was only then that the nation, fed up with water pollution, came to support the Clean Water Act—a federal law that established requirements for sewage treatment. The federal government provided cities with grants and low-interest loans to upgrade their inadequate sewage infrastructure. During the two decades ending in 1992, the federal government invested over $60 billion (about $700 per person today) to again make America's waterways fishable and swimmable.

As these investments in sewage treatment improved the environment, cities continued their struggle to keep up with the demand of growing populations. In addition to building more imported water systems, they turned their attention to conservation and passed laws that required low-flow fixtures and less thirsty landscaping in new housing developments.

But as we soon enter the third decade of the 21st century, two potential crises are again poised to threaten our ability to keep up with thirsty American cities: continued demand and the growing perception by residents of some communities that their tap water is no longer safe to drink.

The availability of water has continued to be an issue as population growth has driven demand. But what is complicating things more than before are climate change-induced shifts in precipitation patterns and a greater recognition that taking too much water from rivers and streams damages aquatic ecosystems. This means that the old model of piping water in from long distances is no longer attractive. For example, the water level in the massive dams on the Colorado River, which supplies some of the drinking water to about 10 percent of the nation's population, has been falling since 2000 due to climactic shifts and increasing demand from cities and farmers. The imminent declaration by the Colorado River's managers of a shortage means that water is about to

get more expensive, and water rights lawyers will become more plentiful in cities throughout the Southwest as legal disputes increase. Recent droughts of historic duration and intensity from Texas to California also have contributed to a sense that action is needed to enhance water security—that simple notion of having enough available, clean water to meet society's needs. Atlanta, Tampa, Florida, and Charlotte, North Carolina, are worrying about the security of their existing water supplies because their populations are approaching a point where local water sources will no longer be sufficient, especially during dry years.

Some communities facing water shortages have begun to think ahead by investing in new strategies for decreasing their reliance on imported water. This movement, which is sometimes referred to as water self-sufficiency, is furthest advanced in Southern California, where water has long been a scarce resource. The 2.5 million people of Orange County now recycle nearly all of their wastewater, passing it through an advanced treatment plant and returning it to the aquifer from which they draw their drinking water. The county currently satisfies 75 percent of its drinking water needs by combining water from wastewater recycling with groundwater recharged with rainwater that falls within the city and water from an effluent-laden stream that bisects the county. If the remaining 25 percent of the region's imported water supply becomes too expensive or unreliable, the county could meet its water needs by building seawater desalination plants, just as its neighbors to the south, in San Diego, and to the north, in Santa Barbara, did in response to their water scarcity concerns.

Elsewhere, the drive toward water self-sufficiency has taken a different form, shaped by local geography and geology. In California's Salinas Valley, technologies similar to those used to recycle wastewater in Orange County are being repurposed to create drinking water from a mixture of municipal wastewater effluent, runoff from city streets and farm fields, and wash water from food processing plants.

On the East Coast, in eastern Virginia, the local utility is treating wastewater with advanced technologies before using it to recharge the local drinking water aquifer. The project makes sense in that relatively wet part of the country because it eliminates the discharge of nutrient-rich wastewater to the ecologically sensitive Chesapeake Bay and counteracts land subsidence that has made the region increasingly vulnerable to flooding from rising sea levels.

The second potential water crisis is related to a growing public perception that tap water is no longer safe to drink. The failure of the municipal water system in Flint to properly manage its aging pipe network, which contaminated the water supply with lead and Legionella bacteria, was national news a few years ago. More recently, the discovery that chemicals used for firefighting and industrial manufacturing—the per- and polyfluoroalkyl substances referred to as PFAS—have contaminated water supplies for about a quarter of the nation has further highlighted the vulnerability of drinking water systems to man-made pollutants.

Most important, this discovery raises a significant new issue: Can our old water filtration and disinfection plants protect public health? Simply retrofitting treatment plants in places where water supplies are known to be contaminated and banning difficult-to-treat chemicals like PFAS will not protect us from the coming quality challenges. Evidence of the systemic shortcomings of the existing drinking water system are apparent a short drive south of Flint, in Toledo, Ohio, where continued release of nutrients from farms, wastewater treatment plants, and city streets, coupled with warmer temperatures in the Great Lakes, resulted in blooms of toxic algae that made tap water unsafe for several days in 2014. The exact cause of more recent toxic algal blooms that have occurred in Florida, Oregon, Ohio, and other parts of the country is unclear, but most experts suspect that nutrients that are legally released from farms and cities are the main culprit. Simply put, our aging drinking water systems are not ready for the less forgiving future that will prevail in an era of climate change and inadequate pollution regulations.

Considering the way that change has come about in the past, it seems likely that the nation will have to weather a few more high-profile drinking water contamination incidents before public opinion forces action. When change does come about, it would be useful if the means of evolving our water systems were ready to be deployed. Using the water self-sufficiency movement as a starting point, it may be possible to rapidly adapt existing infrastructure. For example, the reverse osmosis technology used to make municipal wastewater

effluent and seawater safe to drink by forcing water through a membrane that captures salts, microbes, and chemicals could be repurposed to remove PFAS and algal toxins from water supplies. With a little more development, emerging technologies that have yet to be deployed at scale, such as energy-efficient LED water disinfection lamps and treatment systems that use electricity instead of difficult-to-manage chemicals to decontaminate water, could provide new approaches for solving water-quality problems. Although advanced treatment technologies will not solve all of the problems related to decaying water pipes, aging dams, and inadequate treatment plants, they may create the means to move away from our historic reliance on massive infrastructure projects that have become too expensive to properly maintain.

For example, point-of-entry water filters that purify only the water that comes into the kitchen and building-scale water recycling systems that clean up any contaminants that entered the water within the underground pipe network could reduce costs by allowing water used outdoors for cleaning and irrigation to be treated less stringently than drinking water. Additional savings could be realized by investments in underutilized technologies that prevent treated water from escaping from aging water pipes between the treatment plant and the user.

Given these needs, our nation's water systems are on the cusp of a once-in-a-generation change involving costs that could reach $100 billion. Whether the change is preceded by crises that compromise public health and damage local economies will depend upon the investments that are made over the next few years. Federal agencies, including the National Science Foundation and the Department of Energy, along with water-stressed cities in Southern California and Texas, have begun to invest in the research and development needed to adapt urban water infrastructure to a future with greater water scarcity and increasing threats to water quality. Elected officials and community leaders now must recognize that they have an important role to play in reforming the institutions, regulations, and financial policies that impede systemic change. Our history of crisis and response will likely continue, but the more we can anticipate and plan, the better the chance that we'll have the safe water we all need in a less forgiving future.

Vertebrates on the Brink as Indicators of Biological Annihilation and the Sixth Mass Extinction

Gerardo Ceballos, Paul R. Ehrlich, and Peter H. Raven

The ongoing sixth mass species extinction is the result of the destruction of component populations leading to eventual extirpation of entire species. Populations and species extinctions have severe implications for society through the degradation of ecosystem services. Here we assess the extinction crisis from a different perspective. We examine 29,400 species of terrestrial vertebrates, and determine which are on the brink of extinction because they have fewer than 1,000 individuals. There are 515 species on the brink (1.7% of the evaluated vertebrates). Around 94% of the populations of 77 mammal and bird species on the brink have been lost in the last century. Assuming all species on the brink have similar trends, more than 237,000 populations of those species have vanished since 1900. We conclude the human-caused sixth mass extinction is likely accelerating for several reasons. First, many of the species that have been driven to the brink will likely become extinct soon. Second, the distribution of those species highly coincides with hundreds of other endangered species, surviving in regions with high human impacts, suggesting ongoing regional biodiversity collapses. Third, close ecological interactions of species on the brink tend to move other species toward annihilation when they disappear—extinction breeds extinctions. Finally, human pressures on the biosphere are growing rapidly, and a recent example is the current coronavirus disease 2019 (Covid-19) pandemic, linked to wildlife trade. Our results reemphasize the extreme urgency of taking much-expanded worldwide actions to save wild species and humanity's crucial life-support systems from this existential threat.

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During the more than 4.5 billion years of Earth's history, there has never been a richness of life comparable to that which exists today[1]. Although there have been five mass extinction episodes during the last 450 million years, each destroying 70 to 95% of the species of plants, animals, and microorganisms that existed earlier[2–4], life has recovered and multiplied extensively. Those extinction events were caused by catastrophic alterations of the environment, such as

Significance

The ongoing sixth mass extinction may be the most serious environmental threat to the persistence of civilization, because it is irreversible. Thousands of populations of critically endangered vertebrate animal species have been lost in a century, indicating that the sixth mass extinction is human caused and accelerating. The acceleration of the extinction crisis is certain because of the still fast growth in human numbers and consumption rates. In addition, species are links in ecosystems, and, as they fall out, the species they interact with are likely to go also. In the regions where disappearing species are concentrated, regional biodiversity collapses are likely occurring. Our results reemphasize the extreme urgency of taking massive global actions to save humanity's crucial life-support systems.

massive volcanic eruptions, depletion of oceanic oxygen, or collision with an asteroid[5]. In each case, it took millions of years to regain numbers of species comparable to those that existed before the particular extinction event[6,7]. Even though only an estimated 2% of all of the species that ever lived are alive today, the absolute number of species is greater now than ever before[2]. It was into such a biologically diverse world that we humans evolved, and such a world that we are destroying.

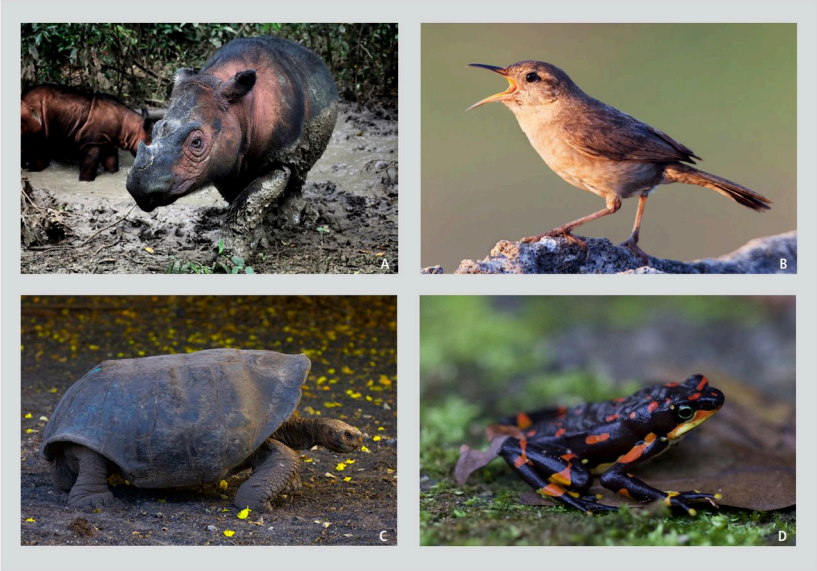

Figure 1: Terrestrial vertebrates on the brink (i.e., with 1,000 or fewer individuals) include species such as (A) Sumatran rhino (Dicerorhinus sumatrensis; image credit: Rhett A. Butler [photographer]), (B) Clarion island wren (Troglodytes tanneri; image credit: Claudio Contreras Koob [photographer]), (C) Española Giant Tortoise (Chelonoidis hoodensis; image credit: G.C.), and (D) Harlequin frog (Atelopus varius; the population size of the species is unknown but it is estimated at less than 1,000; image credit: G.C.).

Life has now entered a sixth mass extinction (8–10). This is probably the most serious environmental problem, because the loss of a species is permanent, each of them playing a greater or lesser role in the living systems on which we all depend[11,12]. The species extinctions that define the current crisis are, in turn, based on the massive disappearance of their component populations, mostly since the 1800s[10,13–20]. The massive losses that we are experiencing are being caused, directly or indirectly, by the activities of Homo sapiens. They have almost all occurred since our ancestors developed agriculture, some 11,000 y ago. At that time, we numbered about 1 million people worldwide; now there are 7.7 billion of us, and our numbers are still rapidly growing[21]. As our numbers have grown, humanity has come to pose an unprecedented threat to the vast majority of its living companions.

Today, species extinction rates are hundreds or thousands of times faster than the “normal” or “background” rates prevailing in the last tens of millions of years[8–10]. The recent United Nations report on biodiversity and ecosystem services estimates that a quarter of all species face extinction, many within decades[11]. When a species disappears, a wide range of characteristics is lost forever, from genes and interactions to phenotypes and behaviors[22–27].

Every time a species or population vanishes, Earth’s capability to maintain ecosystem services is eroded to a degree, depending on the species or population concerned. Each population is likely to be unique and therefore likely to differ in its capacity to fit into a particular ecosystem and play a role there. The effects of extinctions will worsen in the coming decades, as losses of functional units, redundancy, and genetic and cultural variability change entire ecosystems[14,23,24]. Humanity needs the life support of a relatively stable climate, flows of fresh water, agricultural pest and disease-vector control, pollination for crops, and so on, all provided by functional ecosystems[12,28].

Examples documenting the ongoing biological annihilation are proliferating, each of them underlining the magnitude of the problem and the urgency of taking action. More than 400 vertebrate species became extinct in the last 100 y, extinctions that would have taken up to 10,000 y in the normal course of evolution[10]. Among vertebrate species that have disappeared in historic times are the thylacine (Thylancinus cyanocephalus), the ivory-billed woodpecker (Campephilus principalis), and the RoundIsland burrowing boa (Bolyeria multocarinata). Champions of recent extinctions are amphibians, with hundreds of species of frogs and toads suffering population declines and extinctions: perhaps a fifth of the species extinct already or on the brink of extinction. The symbol of this amphibian holocaust is the loss, soon after it was discovered, of the gorgeous golden toad

(Incilius periglenes), an inhabitant of Costa Rican cloud forests. The principal culprit in the disappearance of so many amphibians so rapidly is a chytrid fungus, sometimes spread from place to place as a result of human activities[29]; this parasite affects populations weakened by climate disruption particularly rapidly[30].

Class	Species	IUCN	Percent
Mammalia	74	5,459	1.4
Aves	335	10,423	3.2
Reptilia	41	6,861	0.6
Amphibia	65	6,631	1.0
Total	515	29,374	1.7

Table 1: Number of species on the brink (i.e., with fewer than 1,000 individuals) and number of species whose conservation status had been evaluated by the IUCN (Version 2019)

Millions of populations have vanished in the last 100 y, with most people unaware of their loss[16]; such losses have become extremely severe in the last few decades[13–20,31,32]. These losses are not simply happening to obscure organisms of little interest to anyone. Instead, they include many populations of large and conspicuous animals and plants, from lions and tigers to elephants and cacti. For example, in a sample of 177 species of large mammals, most lost more than 80% of their geographic range in the last century[13], implying a very extensive extirpation of populations. Similarly, a recent study showed that 32% of more than 27,000 vertebrate species have declining populations[15]. And the Living Planet Report found that roughly 70% of all individuals of vertebrate species have disappeared over the 50 y since 1970[33]. Insects and other invertebrates have suffered huge losses also. About 75% of all flying insects in national parks in Germany disappeared in 25 y[16], and there are numerous signs that many species of insects are heading for the exit[34,35]. Similar losses have been documented for various species of clams, snails, and starfish[36–40] and for plants[19,41]. The process of extinction involves progressive declines in the abundance and geographic range of a species[26]. Smaller populations become more isolated and more prone to extinction from natural (e.g., inbreeding, accident) and human causes[42]. The reason so many species are being pushed to extinction by anthropogenic causes is indicated by humans and their domesticated animals being some 30 times the living mass of all of the wild mammals that must compete with them for space and resources[43].

When the number of individuals in a population or species drops too low, its contributions to ecosystem functions and services become unimportant, its genetic variability and resilience is reduced, and its contribution to human welfare may be lost. At a certain point, a population can be too small or too lacking in required habitat to reproduce itself. At one time, the bison (Bison bison) was a keystone species in the prairies of North America, maintaining the entire ecosystem, supplying, at various stages, meat, robes, and fertilizer to Native Americans, and later to Europeans. Indeed, it is estimated that, two centuries ago, there were probably some 30 to 60 million of these large mammals roaming the plains of the continent. Overharvesting for meat and skins, and prairie ecosystems converted to farming, exterminated most populations. By 1884, only some 325

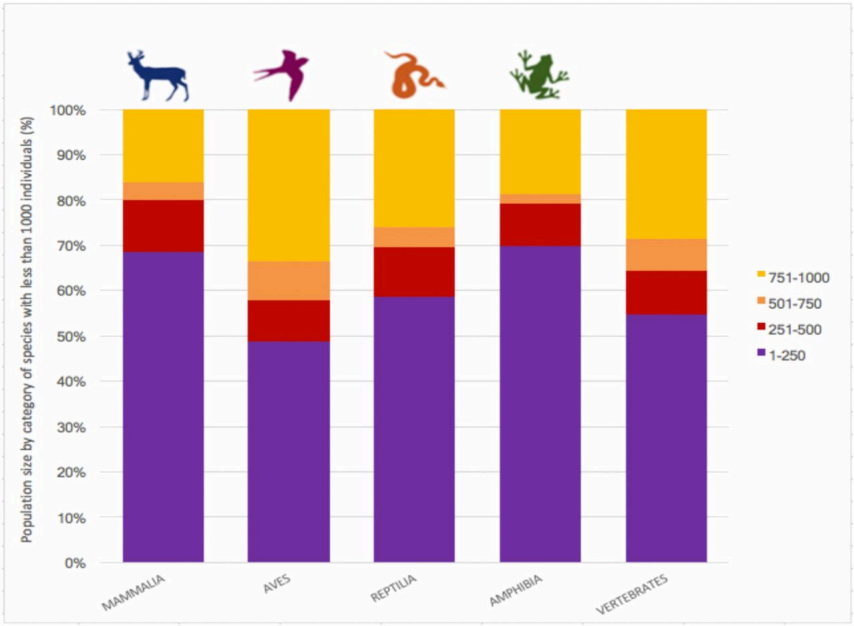

Figure 2: Population size of terrestrial vertebrate species on the brink (i.e., with under 1,000 individuals). Most of these species are especially close to extinction because they consist of fewer than 250 individuals. In most cases, those few individuals are scattered through several small populations.

individuals were left[44]. Subsequently, they have recovered to about 4,000 wild bison, with some 500,000 living in enclosures;the species has certainly not reclaimed its ecological role; in any case, the great majority of North American prairies have been destroyed. In a sense, bison and many other species with tiny populations have become what Janzen[45] has termed, in a slightly different way, "ecological zombies," still there but not significant for ecosystem function.

Class	Africa	Asia	Europe	South America	North America	Oceania
Mammalia	13	22	2	8	12	17
Aves	64	67	4	86	28	85
Reptilia	2	12	0	10	12	5
Amphibia	3	5	0	53	3	1
Total	82	106	6	157	55	108

Table 2: Distribution of species on the brink (i.e., with fewer than 1,000 individuals) across continents

Here we add to our studies of the sixth mass extinction[9,10,13–16,42]. We analyze the status of vertebrates that we judge are on the brink of extinction. Most of these have lost the majority of their geographic range, and most of their populations, and now have fewer than 1,000 individuals (referred to as "on the brink" or "under 1,000" hereafter). Examples of those species are shown in Fig. 1. We then compare the distribution patterns of these species on the brink with those slightly more secure—species estimated to have more than 1,000 but less than 5,000 individuals (referred as "under 5,000" hereafter). We chose terrestrial vertebrates because they are the animals most familiar to people and because there are more data on their conservation status than on those of most other organisms. And we pick, as a center of discussion, a round number of individuals, 1,000, which is the population size at which the International Union for Conservation of Nature (IUCN) ordinarily lists species as "critically endangered." So, we specifically address the following questions about the species on the brink: 1) Which are the vertebrate species on the brink? 2) What are the historic and current patterns of distribution of those species? 3) How many populations have they lost in historic times? 4) How do these patterns compare with those of the slightly more secure species—those under 5,000 individuals? The answers to these questions should allow us, in principle, to take effective action to save the species concerned from extinction, but, to succeed, our efforts must be prompt, determined, and widespread. We need to undertake such efforts to have any chance of reversing the biological annihilation that is underway.

Results

Vertebrates on the Brink of Extinction. Our results underline the magnitude of the extinction crises at both species and population levels. Although the data are necessarily incomplete, at least 1.7% of the species of terrestrial vertebrates—515 of them—have fewer than 1,000 remaining individuals, that is, are on the brink (Table 1 and Fig. 2). Those 515 species represent, however, a staggering quarter of the species, both common and rare, that have population data. Among these under on the brink, 243 (47%) are continental and 272 (53%) are insular. Most of the species are from South America (157 species [spp], 30%), followed by Oceania (108 spp, 21%), Asia (106 spp, 21%), Africa (82 spp, 16%), North and Central America (55 spp, 11%), and Europe (6 spp, 1%). The greatest numbers of mammals on the brink occur in Asia and Oceania, while most birds on the brink live in South America and Oceania (Table 2). The reptiles with very small populations occur mainly in North America and Asia, while the amphibians are in the Americas. Proportionally, more bird species are on the brink, followed by amphibians, then mammals, and reptiles.

Population sizes of the species on the brink are often much smaller than 1,000 individuals (Fig. 2). Indeed, more than half of these species are estimated to have been reduced to 250 or fewer individuals (Fig. 2). The number of species with 250 or fewer individual in mammals and amphibians is even higher, with roughly two-thirds in this category. Species on the brink are concentrated, not surprisingly, in areas highly impacted by humans (Fig. 3). Different groups display diverse geographic patterns. Bird species on the brink are more widespread than those of other vertebrates (Fig. 3). But the majority of all vertebrates on the brink are found in tropical and subtropical regions in the Americas, Africa, and Asia. Those are areas with relatively rich biotas, with many endemic species, and smaller populations, on the average, than the species of the vast north temperate regions of the globe.

The Road to the Brink: From 5,000 to 1,000 Individuals. The distributions of the 388 species comprising the under 5,000s and of those at the brink (i.e., under 1,000s) show a near-universal distribution, the main exceptions being temperate and subarctic regions of the Northern Hemisphere (Fig. 4). Those species are concentrated largely in tropical regions. The distribution of those on the brink and the under 5,000s shows a significant concurrence; an impressive 84% of the under 5,000s species are found in the same regions as the species on the brink. The congruence is further evidence that the present sixth mass extinction is human caused, something further indicated by what seems to be an incipient regional biodiversity collapse in those areas. As population extinctions continue, some of the species on the brink will likely become extinct, and some of the under 5,000s will move onto the brink.

Mass Extinction of Populations: Comparing Historic and Current Range. Species at the brink have lost most of their populations and individuals. To gain insights into the extent and significance of population extinction, we compared the historic and current distributions of both 48 species of mammals and 29 species of birds on the brink; mammals and birds were the only groups for which such data were available (Fig. 5). These comparisons show a huge reduction of the historic geographic range of those species, representing a massive loss of populations too. Vast areas in Europe, northern Africa, the Middle East, Australia, and North America have lost most of those mammals and birds that are now on the brink. Assuming that an average mammal or bird population occupies 10,000 km^2,[13] our data suggest that, during the last two centuries, of the 48 mammal and of the 29 bird

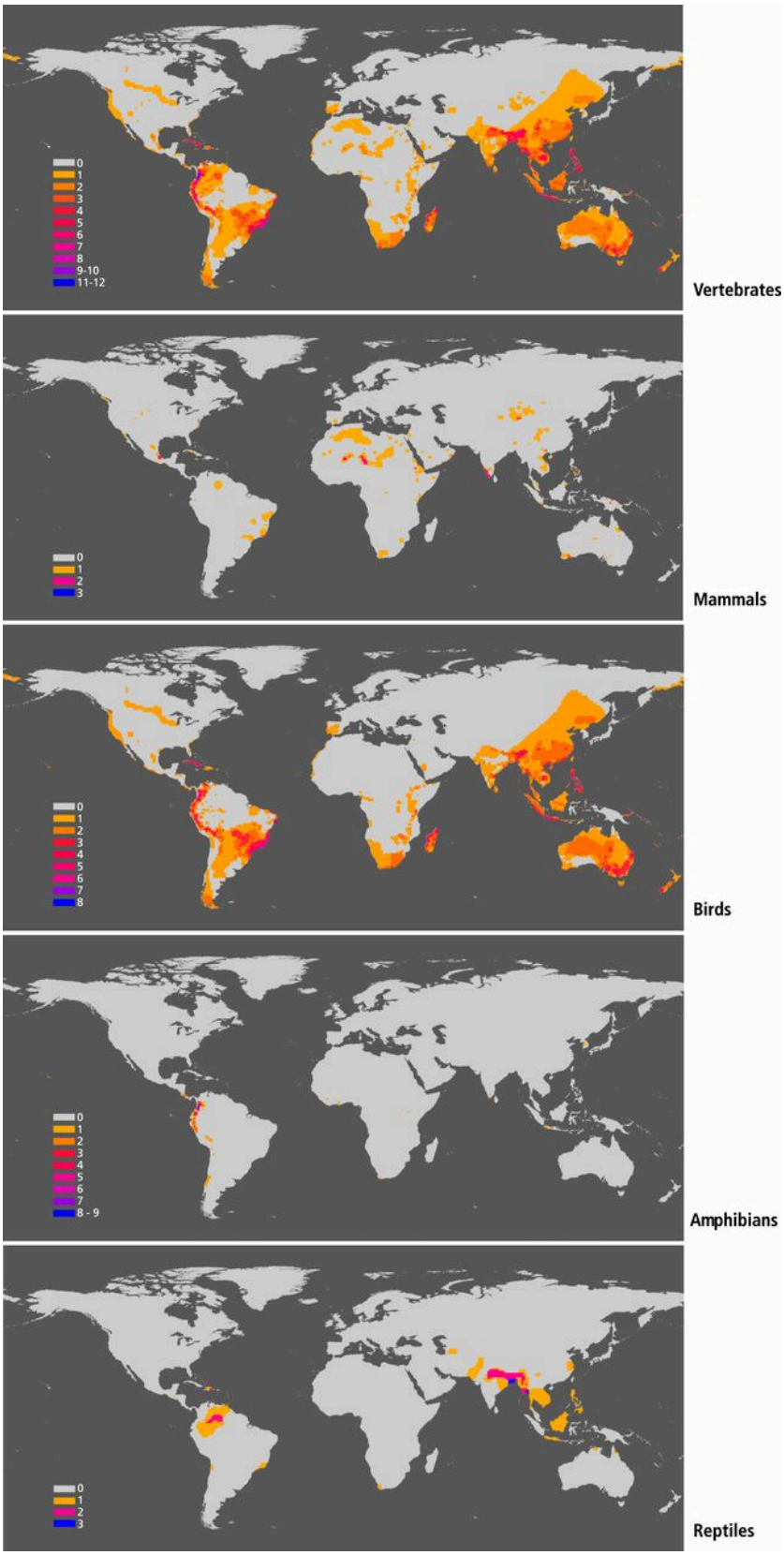

Figure 3: Geographic distribution terrestrial vertebrate species on the brink (i.e., with under 1,000 individuals). The colors in the left bar indicate the number of species in a 100 square km global cell grid.

species we examined, roughly 3,600 populations of the 48 mammal species and 2,930 populations of the 29 bird species have disappeared. Those mammal and bird species have lost an average 95% and 94% of their geographic range since 1900. If we assume a similar reduction of the historic range of all of the 515 vertebrate species on the brink, then a staggering 237,000 populations of their populations have disappeared since 1900.

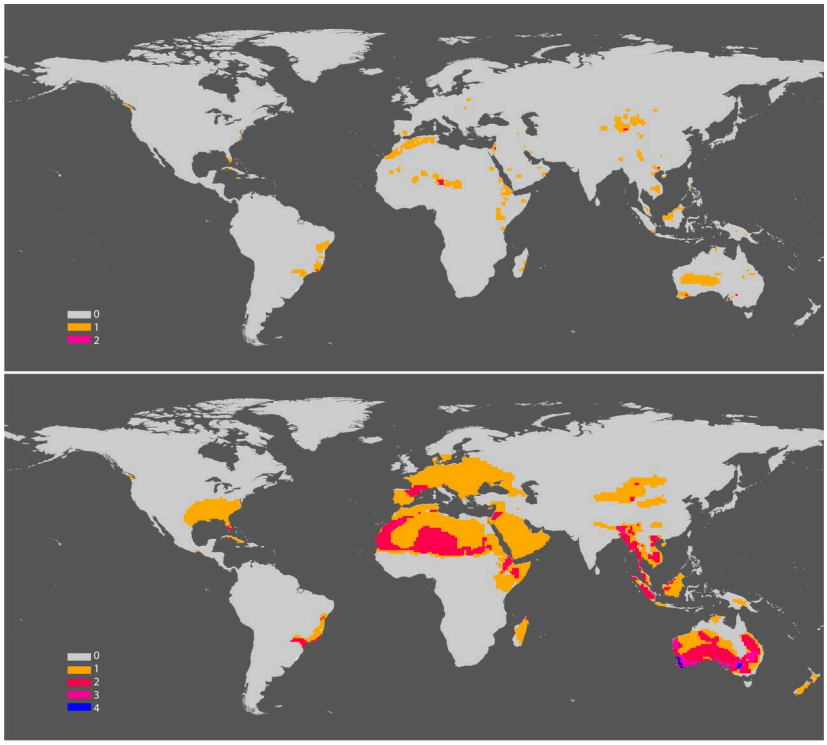

Figure 4: Historic (Top) and current (Bottom) geographic range of 48 mammal and 29 bird terrestrial species on the brink (i.e., with under 1,000 individuals). Note the high concentration of species in tropical regions throughout the world.

Mass Extinction of Species: Accelerated Human-Induced Rates. The species on the brink could soon be joining the ~543 species of vertebrates that are known to have disappeared since 1900[46]. Suppose, as a thought experiment, that the species at the brink will become extinct by the year 2050. Then the sum of 543 already extinct and those on the brink projected to disappear would be 1,058 vertebrates. Under the last 2 million years' background rate, 2 species would be expected to become extinct in a century for every 10,000 species[8]. Therefore, for the 29,400 vertebrate species evaluated in our study, one would expect 9 extinctions in the 150 y between 1900 and 2050. Instead of the 9 expected extinctions in the hypothetical scenario, 1,058 species would become extinct by 2050. So, the extinction rate by 2050 would be 117 times higher than the background rate. Therefore, the species extinct in those 150 y would have taken 11,700 y to become extinct under the background extinction rate.

Discussion

Our results provide important conservation insights. First, as the status of any species changes from common to being on the brink of extinction, its gradual loss will bring pressures to bear on other species with which it interacts. Clearly, the loss of so many populations has caused major changes in the ecosystems they inhabit and doubtless contributed concurrently to the extinction of other species in those ecosystems. At times, these losses must have triggered the substantial alteration of ecosystems structure and function[11,12]. Extinction cascades, a series of extinctions triggered by the disappearance of a keystone species in an ecosystem, occur frequently, as shown by the classic case of Steller's sea cow[47]. Obviously, the loss of species and populations drives the loss of their specialized parasites. A dramatic example was the discovery and description in 2005 of six new species of mites found among the feathers of museum specimens of the long extinct Carolina Parakeet (Conuropsis carolinensis)[48]. Similarly, closely linked pairs of species involved in relationships like pollination may become extinct simultaneously[49–51]. Thus, moving onto the brink is an important part of the process of defaunation[14].

Second, documenting so many species on the verge of collapse has led us to suggest that future rates of extinction are probably underestimated. As our results indicate, the current rapid vertebrate extinction rate will itself increase sharply in the future. So, predictions that one-fifth of all species would be in danger of extinction by midcentury and half or more by the end of the century begin to make sense[9–11].

Third, concentrations of species at risk for extinction, with the geographical congruence in distribution of the

under 5,000s and species on the brink categories, are strong indicators of incipient regional biodiversity collapse in areas such as the Arctic, southeast Asia, and elsewhere. They occur mostly in heavily populated regions such as tropical Asia, where major ongoing biodiversity losses are well known[10,13–15,30,46,52,53].

Fourth, species at the brink have been pushed to a critical conservation status because of human activities, where habitat loss and fragmentation, illegal trade, overexploitation, introduced domestic and wild species, toxification, and pollution have played a major role[10,13–15,30,46,52,53]. More recently, climate disruption is becoming a major cause of species endangerment[10,11,14–17]. We believe that the recent coronavirus outbreak is linked to wildlife trade and consumption in China[54]. The ban on wildlife trade imposed by the Chinese government could be a major conservation measure for many species on the brink, if imposed properly. The ban should include wild species for consumption as food as well as medicinal use and pets.

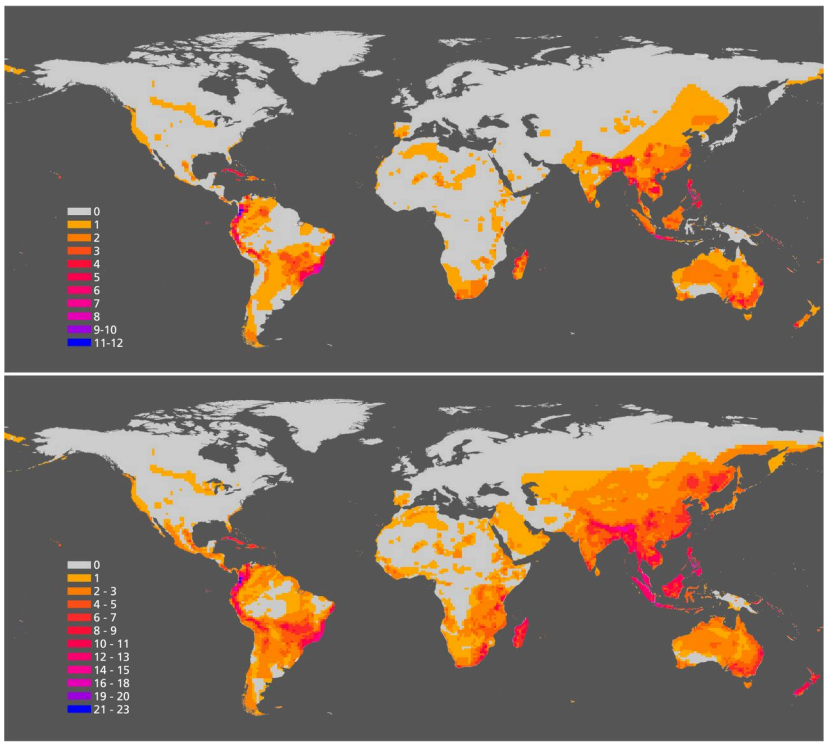

Figure 5: Current distribution of 515 terrestrial vertebrate species on the brink (i.e., with under 1,000 individuals; Top) and 903 species with under 5,000 individuals (Bottom). Of the 388 species under 5,000 that have populations larger than 1,000 individuals, 84% have overlapping distributions with the species at the brink (i.e., with under 1,000 individuals), indicating high distribution congruence.

Finally, major losses of populations and species clearly impede the provision of ecosystem goods and services, with consequent impacts on human well-being[11,12]. The growing human population, increasing rates of consumption, and projected growth in the future can only accelerate the rapid disappearance of species, now a stream, to a rushing torrent—a problem for survival that only human beings have the power to alleviate.

Concluding Remarks

The extinction crisis, like the toxification and climate crises to which it is tied, poses an existential threat to civilization. Although it is more immediate than climate disruption, its magnitude and likely impacts on human well-being are largely unknown by governments, the private sector, and civil society. It is, therefore, a scientific and moral imperative for scientists to take whatever actions they can to stop extinction. For example, in relation to all under 5,000s species, they should be immediately classified by the IUCN as critically endangered. Indeed, the conservation of endangered species should be elevated to a national and global emergency for governments and institutions, equal to climate disruption. Among the possible actions, a global comprehensive binding agreement is required to address the extinction crisis, especially to tackle the legal and illegal trade in wild species. Such an agreement should be a mere first step in developing a 2020–2030 conservation agenda.

Many of the species endangered or at the brink of extinction are being decimated by the legal and illegal wildlife trade, which poses a fundamental threat for human health and well-being, is a major cause of population and species extinctions, and is eroding the ecosystem services that we require to survive. The horrific coronavirus disease 2019 (Covid-19) pandemic that we are experiencing, of which we still do not fully understand the likely economic, political, and social global impacts, is linked to wildlife trade. It is imperative that wildlife trade for

human consumption is considered a gigantic threat to both human health and wildlife conservation. Therefore, it has to be completely banned, and the ban strictly enforced, especially in China, Vietnam, Indonesia, and other countries in Asia[14,42,54]. It is also imperative that steps are taken to provide food for the poor people that conservation measures may deprive of bush meat, especially in Africa[42].

In view of the current extinction crisis and the lack of widespread actions to halt it, it is very important that scientists should metaphorically take to the streets. We have, for example, started a new global initiative we called "Stop Extinction," to address and publicize the extent of the extinction crisis and its impacts on the loss of biodiversity, ecosystem services, and human well-being, aspects still rather ignored by most people[55]. There is time, but the window of opportunity is almost closed.We must save what we can, or lose the opportunity to do so forever. There is no doubt, for example, that there will be more pandemics if we continue destroying habitats and trading wildlife for human consumption as food and traditional medicines. It is something that humanity cannot permit, as it may be a tipping point for the collapse of civilization. What is at stake is the fate of humanity and most living species. Future generations deserve better from us.

Methods

In order to obtain size-based population of global terrestrial vertebrate's information, we acquired database material from the IUCN Red List of Threatened Species and Birdlife International[46,56]. We assembled data on the geographical range of each species, and then classified them within one of the nine categories of the IUCN Red List[46]. On the basis of these data, we determined the number of vertebrate species with a maximum population size of 1,000 individuals. According to the IUCN, the number of individuals is based on the population size measured as the number of mature individuals. We excluded extinct species from our analyses, leaving a total of 515 species, out of which 65 are amphibians, 335 are birds, 41 are reptiles, and 74 are terrestrial mammals (SI Appendix). Distribution ranges of all groups were overlapped and combined to obtain the global maps of number of species (richness) using ARCGIS 10.1. This involved using a Behrmann equal-area grid with a cell size of 96.5 km x 96.5 km (~1° at the equator).

The population extinction analysis was conducted with 48 species of terrestrial mammals and 29 bird species distributed on five continents. The historical distribution was gathered from specialized literature[13], and the spatial data of current distribution were obtained from the IUCN Red List[46] (SI Appendix). The historical and current distribution ranges were overlapped to obtain the global maps of number of species using ARCGIS 10.1. For the 48 terrestrial mammal and 29 bird species, we calculated the area of the historical and current geographic distribution ranges to estimate the lost area and the area where species currently are distributed (in square kilometers).

Data Availability. All data are available within the manuscript and in SI Appendix.

ACKNOWLEDGMENTS. We thank our friends and colleagues who helped us with data gathering and analysis. The assistance of E. Joaquin Romero was instrumental for the data analysis of species distribution. Paola Guadarrama assisted us in constructing the original database, and Andres Garcia commented on the manuscript and provided us with some of the maps of the declining bird species. Nick Haddad made helpful comments on a previous draft of the manuscript. Rosalba Becerra designed the final figures. The work of G.C. was partially supported by the Programa de Apoyo a Proyectos de Investigación e Innovación Tecnológica (PAPIIT) Project IN208017 and a sabbatical scholarship from Dirección General Asuntos del Personal Académico (DGAPA) of the Universidad Nacional Autonóma de México.

"Vertebrates on the Brink as Indicators of Biological Annihilation and the Sixth Mass Extinction" was originally published in *Proceedings of the National Academy of Sciences of the United States of America.*

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Lessons Learned from U.S. Cities' Climate Adaptation Implementation Methods

Lykke Leonardsen

Editor's Note: Cities are being negatively impacted by climate change – a trend that is only expected to worsen. How are cities coping with and planning for these climate change impacts? Lykke Leonardsen, in cooperation with The German Marshall Fund of the United States, explores the strategies of several U.S. cities and their compatibility to Denmark's climate adaptation efforts in the paper titled "Implementation of Climate Change Adaptation Solutions in U.S. Cities." The paper distills four case studies conducted on Seattle, Portland, Philadelphia, and New York City's tactics on combating climate change. This summary prepared by the editors provides an overview of mitigation and adaptation methods and considerations facing all four cities with a focus on Philadelphia's case study.

Ms. Lykke Leonardsen has worked with urban development for the past 25 years in Copenhagen. This includes local regeneration projects, international urban policies and communication. Since 2008 she has worked for the Technical and Environmental Administration in charge of making Copenhagen more blue and green – in charge of water management and green infrastructure planning. It was as part of this work that the city's Climate Change Adaptation plan was developed.

From 2014-2016, she was the Head of the Climate Unit, in charge of the Climate Change Adaptation program, and the city's ambitious plan to be the first carbon neutral capital of the world before 2025. Since 2016, she has been Head of program for Resilient and Sustainable City Solutions. Ms. Leonardsen has a Master in Near Eastern Archaeology and Master of Public Policy.

I. Introduction

Copenhagen's development of its own climate adaptation plan prompted the examination of other cities' climate adaptation and mitigation strategies. The examination is meant to provide guidance to the Denmark's fight against climate change but can be applied to numerous cities worldwide. The paper examined how these four cities are "managing the twin issues of storm water management in the case of extreme weather events and coastal protection in the case of storm surges."[1]

The foundational differences and similarities among cities lie with the governance structure, financing capacity and resources, and location of each city. Therefore, this paper examines how governance, financing, and location impact each city's reaction to climate change. It also analyzes the lessons learned from the United States and contemplates how they can be transported to a European setting – namely Denmark.

II. Climate Adaptation vs. Mitigation

Adaptation and mitigation are two different methods of addressing climate change impacts. Adaptation applies to a city's efforts to physically adapt to the impacts of climate change as well as make cities more resilient to climate-related disasters (e.g. fortifying cities against rising sea levels or implementing systems to manage increasing amounts of rainfall). Mitigation concentrates on actions to reduce overall greenhouse gas emissions.

Mitigation has a global focus of keeping the world's temperature at reasonable level to keep the planet inhabitable for future generations. Alternatively, adaptation is locally orientated – working to protect

[1] Lykke Leonardsen, *Implementation of Climate Change Adaptation Solutions in U.S. Cities,* The German Marshall Fund of the United States, 3 (2017).
[2] Lykke Leonardsen, at 2.

and improve the city for its residents and local businesses against climate change. Tension exists between these two approaches because some see using adaptation strategies as negating the purpose of mitigation. The paper's author contends that "in a city's quest to manage climate change, one approach cannot necessarily take place at the expense of the other. Indeed, perhaps the most realistic strategy moving forward it to think of ways to adapt while mitigating."[2]

III. Drivers of Climate Change Adaptation in the United States

There is not a consensus in the United States on how to address the threat of climate change. Some cities are realizing that swift action needs to be taken where the federal government has been absent. City officials in the cities identified in the report in particular are focused on dealing with climate change and reducing carbon emissions.

However, these cities differ in their approaches to dealing with climate change. Namely, whether cities should incorporate mitigation, adaptation, or both into their planning. In Seattle and Portland, officials and organizations advocate for mitigation to be the primary focus and are concerned that working on adaptation undermines efforts to reduce overall carbon emissions.

Clearly communicating climate change to both political levels and citizens is critical to driving climate change action. Communicating mitigation differs greatly from communicating adaptation. Mitigation's goal of reducing carbon emissions is not immediately visible and is often associated with giving up something to reach a reduction target. On the other hand, adaptation is tangible and the benefits can be observed immediately (e.g. building a flood protection barrier).

IV. Key Aspects of Adaptation

This paper examines four main policy areas: (1) program and project, (2) capturing co-benefits from adaptation, (3) civic engagement, (4) zoning and building regulations that govern adaptation and mitigation.

1. Program and Project Management

All four cities have developed programs for implementing green infrastructure and integrated these programs into their general stormwater management program. In each case, this program is executed through the city's public utilities. In most cities, these are housed in departments for the environment. In Seattle, Portland, and Philadelphia the mitigation team is located in the same place as adaptation work.

Similarly, Copenhagen has a one climate unit with two teams working on both mitigation and adaptation. Copenhagen has 600,000 inhabitants with a climate team of 24 full-time staffers. While the other cities, excluding New York City, have much smaller staffs and access to resources. For instance, Philadelphia has 1.5 million inhabitants and has an office of only 6 full-time staffers who cover a broader range of topics than Copenhagen's office. Due to the limited number of staffers devoted to this topic other tactics become important including negotiating, networking, and facilitating coordination among other city administration offices and outside partners.

Funding for green infrastructure measures are usually paid for by stormwater taxes or fees. This fee can typically be reduced by either disconnecting from the public sewer system or using ways to logically manage storm water (e.g. creating rain gardens). For example, Portland has a program that diverts downspouts from sewers into water collection tanks and rain gardens.

Philadelphia and Portland have created extensive green infrastructure design and maintenance manuals that are being constantly revised as new lessons are learned. "These manuals are an important source of knowledge for other cities – in and outside the United States – on how to work with green infrastructure programs."[3]

Financing and maintaining green infrastructure have benefits as well as issues. There is debate as to how the

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[3] Lykke Leonardsen, at 6.

water fees paid by residents should be used. And while upfront costs for building green infrastructure are cheaper than traditional grey infrastructure, the long-term upkeep costs can be significant.

Green infrastructure is exposed to the elements and usually catches garbage, which requires new soil and plants – driving up maintenance costs. Traditional maintenance of sewer pipes can merely be flushed out once every couple of years. Because these maintenance measures are vital for allowing green infrastructure to function, properly paying for them is essential. Thus, cities are continuously reevaluating green infrastructure maintenance costs.

As a result, many cities are looking for ways to drive down maintenance costs. In Philadelphia, for instance, the city integrated underground water storage with a tree planting program that requires minimal maintenance since there is no green ground cover. This kind of simple cost reduction is significant for a city with limited resources.

2. Capturing Co-Benefits

Aside from New York City, climate adaptation has not been a high priority for the other cities. A way to raise awareness about adaptation programs is to find co-benefits between adaptation and mitigation. The idea is to discover ways climate adaptation measures can also mitigate other urban development issues simultaneously. For instance, Seattle's stormwater program is closely linked to the restoration of its rivers and streams to benefit wild salmon. New York City utilizes co-benefits by creating more green streets that provide rain beds to drain water and provide shade to cool the city.

Social considerations are also crucial to implementing adaptation measures. Portland has a project, the Johnson Creek project, that uses vegetation and reconnecting the natural flow of a creek to prevent flooding in a socially vulnerable part of the city. New York City's Dry Line project creates ten miles of flood protection around the Lower East Side of Manhattan – an area with a high risk of storm surges and high density of public housing.

3. Civic Engagement

Civic engagement in Denmark differs greatly from the United States in developing and adapting climate change measures. The United States has a strong tradition of voluntary work on these projects including using citizen-created rain gardens and voluntary green infrastructure maintenance. This volunteerism is likely not applicable to Copenhagen where unions would take issue with using volunteers over paid employees.

The United States also more actively involves civic engagement in the development process of climate and adaptation policies. For example, in Seattle the city outsourced green infrastructure development to local grassroots groups. This allows for local buy-in but Denmark typically would keep the work in the hands of the city officials.

U.S. cities also work more closely with local universities in comparison to Denmark. Local universities are a huge source of recruitment for U.S. climate offices and many times city employees teach or conduct research at local universities. In Denmark, research is usually separated from practical work in cities.

4. Zoning and Building Regulations

Zoning and building regulations can aid efforts to reduce climate-related risks such as coastal flooding. Building regulations in particular are important for those living in flood zones. The Federal Emergency Management Agency (FEMA) requires building in flood zones to be elevated, however, this is difficult to implement in densely built urban areas like New York City. As a result, New York City has focused more on the protection of existing buildings through flood protection measures (e.g. flood gates). Hurricane Sandy taught the city that moving basic installations like electricity and water higher up and out of the way of floodwaters could reduce damages and speed up storm recovery. A simple yet effective tool to combating climate impacts in urban areas that could be mirrored elsewhere.

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[4] Lykke Leonardsen, at 11.

V. Philadelphia Case Study

Philadelphia is located on the East Coast of the United States, along the Delaware River. It has a population of 1.5 million residents and over six million living in the greater metro area, making it the fifth largest city in the United States. It is also a port city sitting at the intersection of two rivers.

Philadelphia has one of the highest poverty rates in the nation as well as a low tax base. This economic and social situation is starting to improve with new investments and a new influx of residents, but the city is still struggling. In spite of these issues, the Philadelphia case study "proves that innovation and political courage can make a difference."[4]

1. Expected Impacts of Climate Change

The East Coast will be hit harder by climate change than the West Coast. This is because the East Coast faces the dual threats of rising sea levels and increased heavy rainfall and temperatures. Many of these climate impacts have already begun. For example, since 2010 Philadelphia has had its snowiest winter, two warmest summers, its wettest month, and two hurricanes. Addressing climate change is extremely important but is difficult due to the city's ongoing economic and social challenges as well as its capacity issues.

2. Organization

Philadelphia's Office of Sustainability has only six full-time employees with the main task of ensuring that climate change adaptation and sustainability are integrated into other city departments. In 2009, the city published its ambitious sustainability plan, titled *Green Works*.[5] The plan does not directly account for climate adaptation but green stormwater management is a focal point of the plan. After Hurricane Sandy, the Office of Sustainability incorporated climate adaptation methods into their work in its 2015 report *Growing Stronger*.[6] This report focused on both climate change and potential adaptation strategies.

3. Actions

Philadelphia is focused on stormwater management because the city faces more frequent storms and the accompanying precipitation. Prompted by EPA demands to reduce sewer overflow, and learning from Portland's efforts, Philadelphia launched its "Green City-Clean Waters" plan in 2011.[7] The plan proposed transition from traditional grey infrastructure to green infrastructure. This proposal offered huge economic savings to the city since green infrastructure would cost less than $3 billion while grey infrastructure would cost $8 billion. Philadelphia's approach illustrates holistic thinking that saves costs while creating climate benefits, improving urban landscape, and managing stormwater.

Philadelphia has also worked across sectors to incorporate green infrastructure into other projects. For example, a project to build new green schoolyards in public schools was integrated into stormwater management plans. This shows that stormwater management projects can co-finance part of green infrastructure projects.

Climate change adaptation makes up a larger part of daily operations in Philadelphia than any of the other cities. For example, the city is creating an outreach program to property owners and residents in flood zones. The city is also providing financial support for installing sewer backflow prevention in basements. Outside of these examples, Philadelphia's climate adaptation efforts are still growing.

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[5] Mayor Michael A. Nutter City of Philadelphia, Green Works Philadelphia (2009), https://www.phila.gov/media/20160419140515/2009-greenworks-vision.pdf.

[6] Mayor's Office of Sustainability and ICF International, *Growing Stronger: Toward A Climate-Ready Philadelphia* (2015), https://www.phila.gov/media/20160504162056/Growing-Stronger-Toward-a-Climate-Ready-Philadelphia.pdf.

[7] Philadelphia Water Department, *Green City, Clean Waters*, https://www.pwdplanreview.org/stormwater-101/green-city-clean-waters#.

4. Lessons Learned

Philadelphia holds two lessons that can be adapted to the Copenhagen. First, a great deal can be accomplished with very little funding. "Integrated planning and thinking can go a long way in achieving citywide impacts by making sure that every dollar spent is spent in such a way that it impacts more than one purpose."[8]

Second, taking the time to develop thoughtful strategies is vital because it allows for more complete responses. Philadelphia has been able to conduct a detailed sectorial risk and vulnerability assessment that would not be possible if the process was rushed. Patience and methodical planning are key to achieving a truly sustainable and holistic approach to climate adaptation.

VI. Recommendations

Below are policy recommendations based on the four case studies for Copenhagen's, as well as other similarly situated cities, climate adaptation strategy:

- The design process must account for higher than expected green infrastructure maintenance costs over time.
- While climate change impacts are being felt now, they do not happen overnight. Thus, planning for climate change can be done over time in a thoughtful and thorough process. The key is to incorporate flexibility into planning and adjust the adaptation plan accordingly.
- An extensive vulnerability assessment of proposed adaptation plans is crucial to understand the effects on complex city systems.

Rather than focus on intense, immediate action after a single disaster these cities are choosing to create systems that can handle climate change impacts (e.g. more stormwater) over time. For example, a system built to manage a ten-year storm can be gradually expanded to handle larger events. However, there are drawbacks to this approach including the capacity to handle large events that will inevitably continue to occur in the coming decades (e.g. the final discharge of stormwater). This will be a significant challenge for East Coast cities that face hurricanes with significant storm surges and huge amounts of precipitation.

U.S. cities are forced to be pragmatic in addressing climate change because staff and resources are limited in comparison to Copenhagen. Copenhagen's climate unit has 25 employees while Philadelphia, a city of similar size, has five. Given this situation, these four cities, in particular Philadelphia, have achieved astounding success in combating climate change.

VII. Conclusion

Due to limited resources, U.S. cities are working together and learning from each other. Technical knowledge can be easily transferred from city to city, such as how to best design a rain garden. However, transplanting policy knowledge between countries is challenging since the legislative and financial systems are different for each country. Impressively, without a formal network on exchanging ideas and strategies, these U.S. cities learned and continue to learn from each other.

For more information on "Implementation of Climate Change Adaptation Solutions in U.S. Cities," click here.

[8] Lykke Leonardsen, at 13.

News and Announcements

Renewable Natural Resources Foundation

Donald Boesch is recipient of 2020 Sustained Achievement Award

Donald Boesch is the recipient of RNRF's 2020 Sustained Achievement Award. The award recognizes a long-term contribution and commitment to the conservation and protection of natural resources by an individual.

Arguably, Boesch's most lasting legacy of 40 years of academic and scientific leadership is the influence he has had on his peers and mentoring of early career scientists. His charismatic leadership on scientific advisory committees, particularly his insistence on ensuring diversity and inclusion of early career professionals, has had an immense impact. Committee members and the convening entities have become more effective by observing and following his guidance. Boesch has been an articulate and effective champion for the importance of independent and unbiased science to inform landscape-scale policy and management actions, evidenced by:

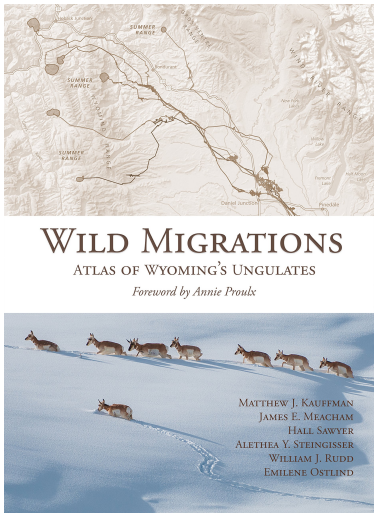
- Ten years energizing and setting the foundation for the Louisiana Universities Marine Consortium as executive director and professor at Louisiana State University. His lifetime interest in the problems of coastal Louisiana include chairing the LCA Science Board, appointment by President Obama to the National Commission on the BP Deepwater Horizon Oil Spill and Future of Offshore Drilling, and as a fellow of the Walton Family Foundation for the future of the Mississippi River Delta.
- 27 years as president of UMCES guiding the growth and establishing UMCES as a trusted source of independent science to guide Maryland policy and management. He established an indelible legacy for the Chesapeake Bay and has been central in addressing wicked problems such as climate change, conservation, nutrient pollution, eutrophication and fisheries management. His role on advisory boards and commissions includes the Chesapeake Bay Program, Maryland Governor's Chesapeake Bay Cabinet (over the terms of five governors), Maryland Climate Change Commission (chairing its scientific and technical working group), and leading the Maryland-Delaware Climate Change Education, Assessment and Research (MADE Clear) program has made him an icon in Maryland. Governor O'Malley honored him as Admiral of Chesapeake Bay.

Internationally, Boesch is a proven leader and has been invited to provide vision on restoration efforts from the Everglades to San Francisco Bay to the Baltic Sea. Notably, he served as chair of the National Academies' Ocean Studies Board.

Over more than forty years of service, he has authored two books and nearly 100 papers cited nearly 15,000 times (Google Scholar) on marine ecology and oceanography of estuaries, wetlands, continental shelves, oil pollution, nutrient-loading, assessment, monitoring and science policy.

He holds a B.S. in biology from Tulane University and a Ph.D. in oceanography from the College of William and Mary.

Wild Migrations: Atlas of Wyoming's Ungulates is recipient of 2020 Outstanding Achievement Award



Wild Migrations: Atlas of Wyoming's Ungulates is the recipient of RNRF's 2020 Outstanding Achievement Award. This award recognizes a project, publication, piece of legislation, or similar concrete accomplishment in the natural resources field.

Wild Migrations: Atlas of Wyoming's Ungulates tells the story of the long-distance migrations that elk, mule deer, moose, pronghorn, bighorn sheep, bison, and mountain goats make each spring and fall across the landscapes of the American West. This book is the definitive synthesis of these epic journeys as seen through the eyes of the biologists and wildlife managers who have studied the ungulates, or hoofed mammals, of Wyoming.

A century and a half ago, the push of western expansion persecuted these great herds, and some were lost. In the early twentieth century, a new ethic of wildlife conservation helped big game populations recover as the West was settled. Today many of these herds again roam Wyoming's mountains and plains. Now for the first time, scientists armed with new satellite technology are discovering and describing ungulate migrations in detail never seen before.

Each spread in this full color book investigates an ecological, historical, or conservation aspect of migration through clear and compelling maps, graphics, and photos. Using a narrative style that is both accessible and scientifically rigorous, this atlas tells the nuanced story of wildlife migration, the scientists who are studying it, and the conservationists who are working to keep wild migrations flowing across western landscapes.

More information about *Wild Migrations* can be found here.

"Concrete: The Most Destructive Material on Earth" is recipient of 2020 Excellence in Journalism Award

"Concrete: The most destructive material on earth," written by the *Guardian's* global environment editor Jonathan Watts, is the recipient of RNRF's 2020 Excellence in Journalism Award. The award honors and encourages excellence in print journalism about natural resources, part of RNRF's goal to advance public education and understanding of important natural resources issues through the dissemination of accurate and scientifically-based information about the environment.

"Concrete: The most destructive material on earth" is an innovative long read about a material that is more ubiquitous than plastic and a bigger source of carbon emissions than all but two of the world's countries. The writer combines jaw-dropping statistical analysis, vivid description and his previous experience as a correspondent in Japan, China and Brazil to reveal the deep flaws in a global development model that relies so heavily on this product.

This article exposes the huge environmental impact of concrete, which has been under-reported for decades. The extraction of the composite elements - sand, aggregate and water - are a growing source of problems, including air pollution, traffic and depletion of river-beds and beaches. Greater still is the loss of fertile land and ecosystems when they are covered in a concrete shell. Watts cites scientific studies, think-tank analysis and landscape philosophy to reveal the implications.

This article, which kicked off the Guardian's concrete week, was - for a while - the most-viewed article on the website with more than 800,000 unique page views and sparked a debate among policymakers, urban planners and architects about switching to alternative building materials, such as cross-laminated timber. It prompted the *Guardian's* Scott Trust to revise its investment strategy to reduce exposure to the cement industry. The story was selected as the best piece published by the *Guardian* in 2019.

The complete article can be found here.

American Geophysical Union

AGU Fall Meeting is Virtual (Mostly) and Remains Global (Always)

We are excited to announce that #AGU20 will be mostly virtual. "Mostly" because if science and health professionals tell us it is safe for groups to convene, AGU would like to host a regional gathering in San Francisco. If we decide that is feasible, we will let you know by August. In addition, depending on where you're located (and if it's safe), you can create your own mini-#AGU20 watch party of hub. We'll share guidance if you're interested in being a convener of one of these mini-#AGU20 regional events.

No matter if we are 100% virtual or if regional gatherings are possible, #AGU20 will remain the global convening meeting for the Earth and space sciences community. And this year, we will be able to engage the wider global community.

For more information, click here.

American Meteorological Society

19th Conference on Mountain Meteorology Virual Meeting

The 19th AMS Conference on Mountain Meteorology will take place in a virtual format. As we are not able to meet in person as planned, we have changed the format of conference to one that is conducive to virtual learning and collaboration. Registered attendees will be able to view prerecorded oral presentations and posters in the online program one week before the conference takes place in order to prepare for live discussions that will take place via GoToMeeting following the keynote talks 13-17 July. There will also be virtual networking opportunities available throughout the week so that attendees can catch up with one another. While we acknowledge that face-to-face interactions are a vital part of our usual Mountain Meteorology Conferences, we hope that this alternate format allows us to share our science and interact with one another as best we can. We hope that by eliminating travel costs and setting registration rates as low as possible, we can maximize participation in the conference.

For more information, click here.

American Society of Civil Engineers

ASCE Recommendations Adopted in House Climate Crisis Action Plan

This week, the Democrats on the House Select Committee on the Climate Crisis released their "Climate Crisis Action Plan," which includes many of the recommendations that ASCE made in our letter to the Committee late last year. Our letter stated, in part:

"Civil engineers work to harden existing and build new infrastructure to better withstand challenges from a changing climate, operating under the assumption that hazard events will continue with increasing regularity and severity. Plainly put, our future depends on resilient infrastructure and – as civil engineers – we think about building infrastructure that will sustainably last for 50 or 100 years or more to maximize lifecycle benefits…

In addition to anticipating what hazards and conditions roads, bridges, drinking water pipes, wastewater treatment plants, airports, and energy lines must withstand, engineers are also thinking through how technology, population shifts, and other trends will change communities' needs. In summary, an integrated systems approach is needed to tackle resiliency."

For more information, click here.

Geological Society of America

Update on The Geological Society of America's 2020 Annual Meeting

The Geological Society of America's 2020 Annual Meeting, formerly scheduled for 25–28 October in Montréal, Québec, Canada, has been recast as a 100% online scientific exchange, taking place over five days, 26–30 October.

GSA 2020 Connects Online will retain many of the traditional features of the in-person annual meeting, including field trips, short courses, technical sessions, poster sessions, the Presidential Address, Feed Your Brain sessions, networking events, GeoCareers opportunities, and the exhibit hall (rebranded as the GSA Resource and Innovation Center)—along with elements that will elicit the flair and feel of the original Montréal location.

For more information, click here.

Society of Environmental Toxicology and Chemistry

Upcoming Special Series: Ecological Consequences of Wildfires

Wildfires play a key role in shaping terrestrial ecosystems by serving as an agent for vegetation renewal and habitat changes. In fact, forestry and wildlife management experts consider wildfires as a part of nature. However, the uncontrolled burning of dry grasses, brush and trees can be quite serious, destroying critical wildlife habitat and valuable timberland and jeopardizing river and stream water quality. Wildfires affect air quality and release carbon dioxide—a key greenhouse gas—and emit particulates into the atmosphere that are potentially harmful to human health. Recovery of the landscape may take decades or longer.

In the spring of 2021, *Integrated Environmental Assessment and Management* will publish a special series on these ecological consequences of wildfires. The series will include papers that contribute to raising global awareness of the consequences of large-scale wildfires and the land management practices needed to prevent such enormous destruction in the future.

For more information, click here.

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