IEEE SA STANDARDS ASSOCIATION

IEEE planet positive 2030

Strong Sustainability by Design

PRIORITIZING ECOSYSTEM AND HUMAN FLOURISHING WITH TECHNOLOGY-BASED SOLUTIONS

FORESTS AND TREES

An initiative supported by the IEEE Standards Association

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Strong Sustainability by Design

This Compendium has been created by committees of the IEEE Planet Positive 2030 Initiative supported by the IEEE Standards Association (IEEE SA). The IEEE Planet Positive 2030 Initiative community is composed of several hundred participants from six continents, who are thought leaders from academia, industry, civil society, policy and government in the related technical and humanistic disciplines. At least one hundred seventy members of this community from about thirty countries have contributed directly to this Compendium and have worked to identify and find consensus on timely issues.

The Compendium's purpose is to identify specific issues and recommendations regarding sustainability and climate change challenges to achieve "Planet Positivity" by 2030, defined as the process of transforming society and infrastructure by 2030 to:

- Reduce Greenhouse Gas (GHG) emissions to 50% of 2005 GHG emissions by 2030.
- Significantly increase regeneration and resilience of the Earth's ecosystems.
- Be well on the path to achieving net zero GHG emissions by 2050 and negative GHG emissions beyond 2050.
- Continue to widely deploy appropriate technology as well as design and implement new technological solutions in support of achieving technological solutions designed and deployed to achieve "Planet Positivity."

In identifying specific issues and pragmatic recommendations, the Compendium:

- Provides a scenario-based challenge (how to achieve "Planet Positivity by 2030") as a tool to inspire readers to get engaged.
- Advances a public discussion about how to build from a "Net Zero" mentality to a "Net or Planet Positive" ("do more good," that is, doing "more" than "don't harm") societal mandate for all technology and policy.
- Continues to build a diverse and inclusive community for the IEEE Planet Positive 2030 Initiative, prioritizing the voices of indigenous and marginalized members whose insights are acutely needed to help make technology and other solutions more valuable for all. Of keen interest is how to encourage more in-depth participatory design in these processes.
- Inspires the creation of technical solutions that can be developed into technical recommendations (for example IEEE SA recommended practice for addressing sustainability, environmental stewardship and climate change challenges in professional practice, IEEE P7800™) and associated certification programs.
- Facilitates the emergence of policies and recommendations that could potentially be intraoperative between different jurisdictions (e.g., countries).

By inviting the general public to read and utilize *Strong Sustainability by Design*, the IEEE Planet Positive 2030 community provides the opportunity to bring multiple voices from the related scientific and engineering communities together with the general public to identify and find broad consensus on technology to address pressing environmental and social issues and proposed recommendations regarding development, implementations and deployment of these technologies. You are invited to Join related IEEE activities, such as standards development and initiatives across the organization.

- For further information, learn more at the IEEE Planet Positive 2030 Initiative website
- Get in touch at: PlanetPositive2030@ieee.org to get connected to and engaged with the IEEE Planet Positive 2030 community.
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A Note Regarding Recommendations in This Document

Strong Sustainability by Design was created in two versions ("draft" and this current edition) that were iterated over the course of two years. The IEEE Planet Positive 2030 Initiative follows a specific consensus building process where members contributing content identify specific potential issues and proposed recommendations.

Membership

IEEE Planet Positive 2030, an initiative supported by the IEEE Standards Association as part of the Industry Connections Program, Sustainable Infrastructures and Community Development program (SICDP), currently has more than four hundred experts involved, and remains eager for new voices and perspectives to join in this work.

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FORESTS AND TREES

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FORESTS AND TREES

Future Vision

It is 2030.

Our natural world is thriving thanks to humankind's sustainable stewardship. In less than a decade, the introduction of robust ecosystem policies, technological breakthroughs, and grass-roots movements have inspired whole generations and communities to protect and restore nature. Humanity was able to turn the tide on the tragedy of the commons—halting and reversing global deforestation, stopping species extinction, massive biodiversity loss, and the overall deterioration of nature.

After years of discussion, the global community decided on science-based regulations that addressed large market failures when it concerns nature conservation and created new models of economic prosperity based on regeneration and climate action.

The creation of robust carbon credits backed by integrity standards and scientific boards raised the level of quality of nature-based solutions. The introduction of a biodiversity index and payments for ecosystem services contributed to nature-based carbon sequestration projects that are biologically diverse, strengthening the overall health of ecosystems.

This not only removed policies that drove deforestation but also created a new and greener business model for local communities to actively reforest around the world and inspired large enterprises to double down on their zero-deforestation commitments.

Citizen-led grassroots movements played an important role. The global ecosystem restoration movement inspired communities around the world to restore and reconnect with nature. At the end of the decade, the movement fulfilled its ambitious goal of planting one trillion biodiverse trees, restoring valuable ecosystems, and preventing ecological tipping points. Large-scale syntropic farming models have been developed and successfully implemented, regenerating healthy agro-ecosystems.

By reconnecting with nature, civilization has rediscovered the vital importance of Indigenous wisdom and communities. There is reciprocity between humans and the natural world. Excessive extraction has been replaced by respect and responsibility for nature's gifts. The "Indigenous renaissance" enabled not only a newfound mutual respect between alternative worldviews but also allowed local communities to legally regain the ownership rights of their ancestral land. Under Indigenous leadership, rainforests are thriving with life and science and business are acquiring knowledge about novel medicines and forest products.

The demand for impact assessment, transparency, traceability, resilience, sustainability, and efficiency in these new markets now drives and supports technological innovation, and, in return, technology delivers. Global satellite data combined with advancements in artificial intelligence allow the transparent tracing and tracking of land-use change and conservation progress all around the world. Additionally, innovations in on-ground and aerial mapping technology empower local communities to map, understand, monitor, and provide better management of their project sites, even in traditionally inaccessible areas below the forest canopy.

Novel field-based sensors such as bioacoustics and environmental DNA collection allow data analysts to measure biodiversity and the richness of life in unprecedented ways to capture even the most concealed of species. Establishing mutual respect and affordable high-speed Internet access will empower local and Indigenous communities to provide valuable information and feedback to decision-makers. They are crucial stakeholders when it comes to deciphering the collected data and providing sustainable, integrated, and resilient solutions.

Economically stable, corruption-free, and ecologically sustainable cryptocurrencies have now become mainstream in many parts of the world when it comes to carbon accounting—providing global and liquid financial access to communities while, at the same time, transparently linking supply chains and carbon credits and remuneration.

Digital citizenship has flourished in emerging economies, creating new paradigms of regenerative wealth creation, where physical natural resources are measured and then transformed into digital wealth. Stewards of nature have received livelihood payments from this pool of natural capital, and there is a vibrant ecotourism industry in space—mediated by virtual reality (VR)/augmented reality (AR)—that brings the value of participating in the immersive travel experiences filmed and captured in these remote regions. Destruction and exploitation of natural resources led to real-time digital penalties, as well as a decrease in community social standing through a social reputational system that became used for international travel and individual social banking.

Advances in legal courts led to the definition of personhood being applied more widely in forestry areas, where entire portions of the forest are considered to be legal persons now. Decentralized community-led conservation groups established closed boundaries that encapsulate large pieces of land and assigned the entire area of the forest to the “body” representing legal personhood.

The global rejuvenation of our natural world has come with immense benefits for all of humankind. People now enjoy reliable access to ecosystem services such as freshwater, flood protection, and clean air, resulting in increased health and happiness benefits. Cities, being immersed in dense urban forests, benefit from the protection from natural hazards such as cool shades during heatwaves. Ecological forestry and early detection of fire risks through technological monitoring have put an end to megafires. To the surprise of many scientists, many endangered species are reappearing in their natural habitat.

Issue 1: Deforestation and forest degradation are key drivers in the climate crisis

Background

Deforestation and land-use change account for 18% of global anthropogenic emissions and contribute to driving up atmospheric carbon levels (IPCC, 2019). Climate change increases the risk of forest fires, creating a vicious cycle for deforestation as well.

Land use is a key component, accounting for approximately 25% of total greenhouse gas (GHG) emissions (Dao et al., 2019). Since 2000, Earth has "lost 361 million hectares of forest cover, equivalent to the size of Europe" (Reiersen et al., 2024).

> *"If tropical deforestation would be a country, it would be the world's third largest emitter (after China and the US). Land use includes a wide range of critical issues, from deforestation and forest degradation to agriculture. The domain is particularly challenging, given that the world's growing population and rising standards of living exert an increasing pressure on food and consumer goods production, both of which may lead to conflicting objectives with climate change and biodiversity."* (Dao et al., 2019)

> *"Forests face increasing risk and frequency of wildfires, droughts, and extreme weather; forest ecosystems are under severe pressure."* (Stephens et al., 2018)

> *"To avoid planetary tipping points (Nobre et al., 2016) and maintain a stable and livable climate…" humankind "…urgently needs to reduce carbon emissions until 2030 and preserve essential ecosystems."* (IPCC, 2021)

> *"Forests and natural carbon sequestration are important climate change mitigation strategies with a biophysical mitigation potential of 5,380 metric tons of carbon dioxide (MtCO2) per year on average until 2050. Forestry is a large industrial sector, and the causes of deforestation are mostly economically driven."* (Nabuurs et al., 2007)

> *"There is thus a need for higher-quality carbon offsetting protocols and higher transparency and accountability of the 'measurement, reporting, and verification'(MRV) of these projects."* (Reiersen et al., 2024)

Recommendations

The technologies listed in the recommendations below offer a range of opportunities to better understand, manage, and protect forests and address the drivers of deforestation. By combining these technologies with effective conservation strategies, it is possible to achieve sustainable forest management and mitigate the impacts of climate change.

1. **Implement quality carbon offsetting protocols and higher transparency and accountability.** "High-quality carbon offsetting protocols and higher transparency and accountability of the MRV of natural carbon sequestration projects" (Dao et al., 2019) should be used as part of the climate change mitigation strategies.
2. **Monitor forests, deforestation, and land use.** Effectively utilize satellite mapping and real-time remote-sensing technologies for the detailed monitoring of forests and deforestation at a local and global scale. By analyzing satellite imagery, researchers and conservationists should track changes in forest cover and identify areas of deforestation in near real time. This technology should also be used to monitor other forest-related variables, such as carbon stocks, biodiversity, and land-use changes.

   Real-time remote-sensing technology enables conservationists to quickly respond to changes in forest cover and take appropriate action to address deforestation. For example, when deforestation is detected, authorities can use this technology to identify the parties responsible and take legal action to prevent further destruction.
3. **Create digital twins to better allow people to see and analyze the data.** Creating digital twins is a powerful tool for visualizing and analyzing data related to forests and deforestation. Digital twins are virtual models that replicate physical objects, systems, or processes. In the case of forests, digital twins can provide a three-dimensional (3D) model of the forest ecosystem, including information on the location, type, and density of trees, as well as other important variables such as soil composition, water availability, and wildlife populations.
4. **Digital twins should be used by conservationists, policymakers, and other stakeholders to gain a better understanding of the complexities of forest ecosystems and the impact of deforestation.** This technology should also be used to simulate the impact of different conservation strategies and identify the most effective interventions to address deforestation.
5. **Employ decentralized ledgers and on-chain representation to record data.** Decentralized ledgers and on-chain representation offer a new way of recording and managing data related to forests and deforestation. By using blockchain technology, data related to forest conservation can be stored in a decentralized and tamper-resistant way, allowing for greater transparency and accountability in the management of forest resources.
6. **Decentralized ledgers should be used to track forest products and the certification of sustainable forestry practices.** This technology enables stakeholders to trace the origin of forest products, verifying that they come from legal and sustainable sources.
7. **Create conversational AI natural language processing (NLP) speech partners representing trees and forests.** Creating conversational AI NLP speech partners representing trees and forests can help to raise awareness of the importance of forests and the impact of deforestation. These AI-powered assistants should be designed to provide information about the benefits of forests, the impact of deforestation, and ways in which individuals can help to protect forests.

The AI-powered speech partners should also be used to educate and engage with children, who are the future custodians of forests. This technology can be designed to use gamification and storytelling techniques to make learning about forests and deforestation fun and engaging.

8. **Support deployment of enhanced MRV of greenhouse gas (GHG) emissions using Internet of Things (IoT) technology.** Enhanced MRV using IoT technology can provide real-time data on forest resources, enabling conservationists and policymakers to make informed decisions about forest management. By using IoT sensors, it is possible to monitor forest carbon stocks, biodiversity, and other important variables in real-time.
9. **IoT technology should be used to monitor and prevent illegal logging and deforestation.** For example, sensors can be used to detect the sound of chainsaws or the movement of logging trucks, enabling authorities to quickly respond to unauthorized activity and help prevent further destruction.

Case studies

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1. Deforestation in the Amazon Rainforest

   The Amazon rainforest is the largest rainforest in the world and plays a critical role in regulating the global climate by absorbing carbon dioxide from the atmosphere. However, deforestation in the Amazon has been occurring at an alarming rate, with an estimated 17% of the forest area lost in the past 50 years. This deforestation is largely driven by cattle ranching, soybean farming, and logging and has led to significant carbon emissions, loss of biodiversity, and changes in regional weather patterns.

   One example of the impact of deforestation in the Amazon is the severe drought that occurred in 2005. Researchers found that the loss of vegetation due to deforestation reduced the amount of water released into the atmosphere through evapotranspiration, leading to a reduction in rainfall and an increase in temperature. This feedback loop resulted in a severe drought that affected millions of people and caused economic losses of over $3 billion (Saatchi et al., 2012).

2. Forest Degradation in Indonesia

   Indonesia is home to some of the world's most biodiverse forests, but the country has been experiencing rapid forest degradation due to illegal logging and conversion of forests for palm oil plantations. Forest degradation refers to the gradual decline in the quality of forest ecosystems, which can lead to a loss of biodiversity, carbon emissions, and changes in local climate patterns.

   In Indonesia, forest degradation has led to the loss of critical habitats for endangered species such as orangutans and tigers. Additionally, the conversion of forests for palm oil plantations has resulted in significant carbon emissions, as well as air and water pollution. The impact of forest degradation is not limited to Indonesia, as the country is a major exporter of palm oil and the demand for this commodity has contributed to deforestation and forest degradation in other countries as well (Riyou, 2016).

3. Deforestation in the Congo Basin

   The Congo Basin is the second-largest tropical forest in the world, and its forests play a crucial role in regulating the global climate by storing large amounts of carbon. However, deforestation in the region has been occurring at an alarming rate, with an estimated 4.3 million hectares lost between 2000 and 2014. The main drivers of deforestation in the Congo Basin are agriculture, logging, and mining.

   One example of the impact of deforestation in the Congo Basin is the loss of habitat for endangered species such as gorillas and elephants. Additionally, deforestation has led to soil erosion, reduced water quality, and changes in local climate patterns. The loss of forest cover also has significant implications for the livelihoods of local communities who rely on the forest for food, medicine, and other resources (Tchatchou, 2015).

Further resources

1. Canadell, J. G., and M. R. Raupach. "Managing Forests for Climate Change Mitigation." *Science* 320 (2008): 1456–1457.
2. Carnicer, Jofre, Andres Alegria, Christos Giannakopoulos, Francesca Di Giuseppe, Anna Karali, Nikos Koutsias, Piero Lionello, et al. "Global Warming Is Shifting the Relationships between Fire Weather and Realized Fire-Induced CO_2 Emissions in Europe." *Scientific Reports* 12 (June 2022).
3. Elbein, Saul. "How Climate Change Is Making Fires Worse." *The Hill*, 24 June 2022.
4. Forzieri, Giovanni, Vasilis Dakos, Nate G. McDowell, Alkama Ramdane, and Alessandro Cescatti. "Emerging Signals of Declining Forest Resilience under Climate Change." *Nature* 608 (July 2022).
5. Le Page, Michael. "Trees Are Dying at Increasing Rates in Forests across Europe." *New Scientist*, 15 Nov. 2021.
6. Nobre, Carlos A., Gilvan Sampaio, Laura S. Borma, Juan Carlos Castilla-Rubio, José S. Silva, and Manoel Cardoso. "Land-Use and Climate Change Risks in the Amazon and the Need of a Novel Sustainable Development Paradigm." *Proceedings of the National Academy of Sciences* 113, no. 39 (Sept. 2016).
7. Vaughan, Adam. "Amazon Rainforest Nears Tipping Point That May See It Become Savannah." *New Scientist*, 7 Mar. 2022.
8. Vaughan, Adam. "Forests Are Becoming Less Resilient Because of Climate Change." *New Scientist*, 13 July 2022.

Issue 2: There is no assignment of value for the existence of nature

Background

"Nature is essential for human existence and good quality of life. Most of nature's contributions to people and their lives are not fully replaceable, and some are irreplaceable" (IPBES, 2019). The natural world is deteriorating at rates unparalleled in human history resulting in a currently ongoing sixth mass extinction.

Forests, especially tropical forests, provide habitats for 80% of land-based biodiversity.

> *"Harmful activities, including habitat destruction, poor farming practices, and pollution, have altered ecosystems significantly, driving many species past the point of recovery… Globally, there are an estimated one million at risk, with biodiversity declining at a faster rate than at any time in human history" (IPBES, 2019).*

"The climate crisis is exacerbating the issue. Many species simply cannot adapt to the scale and pace of changing temperatures" (Vallance, 2022). Furthermore, there is danger of a vicious cycle: biodiversity loss can reduce forest carbon storage and exacerbate climate change, which can, again, spur biodiversity loss. The concept of "nature-based solutions" was pioneered more than two decades ago by the International Union for Conservation of Nature (IUCN) but is now increasing in popularity.

Nature-based solutions (NBS) are "actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature" (IUCN). The 2019 United Nations (UN) Climate Action Summit convened by the UN Secretary-General brought great political attention to the power of NBS. In particular, "the NBS Coalition co-led by China and New Zealand launched the NBS for Climate Manifesto with the support of more than 70 governments and private sector, civil society, and international organizations" and outlining nearly 200 initiatives and best practices on NBS from around the world (UNEP, 2019).

Recommendations

1. **Grow recognition for the value of all ecosystems.** Expand beyond forestry to include grasslands and wetlands, which play vital roles for local and global environments. We should protect the existence of wetlands, grassland, and not blindly plant trees over wetlands and natural grasslands.
2. **View issues in a holistic manner.** Treat the climate and biodiversity crisis as twin crises that affect each other and interact to create complex problems and understand the self-feedback loop between the two crises.
3. **Advocate for restoring natural levels of biodiversity.** Support projects that restore a healthy diversity of native species in any location that should naturally support trees. Monocultures not only capture less carbon but also don't support biodiversity and can even harm nearby ecosystems (ETHzürich, Crowther Lab).
4. **Encourage a forestry credit industry.** Help generate credibility from carbon credits from projects such as forest conservation, reforestation, and agroforestry, which are some of the most common types of nature-based solutions in the carbon market.

5. **Encourage government policies and funding for NBS.** Governments can be encouraged to recognize and promote the value of NBS by implementing policies that support the protection and restoration of natural habitats, including forests. This can include providing funding and incentives for companies and individuals who engage in sustainable forestry practices, as well as implementing regulations that limit deforestation and promote reforestation efforts. Governments can also incorporate NBS into their climate change strategies, highlighting the role that natural solutions can play in mitigating and adapting to the impacts of climate change.
6. **Collaborate with private sector companies.** Private sector companies can be incentivized to recognize and utilize NBS by partnering with conservation organizations and promoting sustainable forestry practices. Companies can be encouraged to adopt policies that promote sustainable sourcing of forest products and engage in reforestation and habitat restoration efforts. Public–private partnerships can also be established to support the development and implementation of NBS projects, providing funding and expertise to support conservation efforts.
7. **Promote education and awareness campaigns.** Education and awareness campaigns can be launched to promote the value of NBS and encourage individuals to engage in conservation efforts. This can include outreach to schools, community organizations, and other stakeholders, providing information on the importance of forests and the benefits of engaging in sustainable forestry practices. Campaigns can also highlight the economic benefits of NBS, such as the creation of jobs in the forestry and conservation sectors and the potential for sustainable tourism.
8. **Develop an open-source monitoring system:** Technologists can leverage their expertise in software and hardware development to create an open-source monitoring system for NBS projects. This system could include IoT sensors, drones, and other technologies to provide real-time data on forest health, carbon storage, and biodiversity. The system could be made available to conservation organizations and communities to support the development and monitoring of NBS projects.
9. **Use AI to predict forest fires:** Technologists can develop AI-powered algorithms to help predict and prevent forest fires. These algorithms could use data from remote sensing technologies, such as satellite imagery and weather data, to identify areas at risk of wildfires. The algorithms could also be used to identify potential fire suppression strategies, such as controlled burns, to prevent the spread of wildfires.
10. **Create virtual reality experiences to showcase NBS:** Technologists can develop virtual reality (VR) experiences that showcase the importance of NBS and the benefits of forest conservation. These experiences could be used in education and awareness campaigns to engage and educate individuals about the value of NBS. IEEE community members with expertise in VR technology could also contribute to the development.
11. **Designing blockchain-based solutions for forest management:** Technologists can design blockchain-based solutions to enable transparent and secure tracking of forest resources, including timber and non-timber forest products. The use of blockchain can provide a tamper-resistant record of forest products, enabling stakeholders to trace the origin of forest products and help verify they come from legal and sustainable sources.

Case studies

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1. Costa Rica's Payments for Environmental Services Program

   Costa Rica's payments for environmental services (PES) program (PAS in Spanish) is a nature-based solution that provides financial incentives to landowners who engage in conservation efforts. Under the program, landowners receive payments for preserving forests, protecting watersheds, and other conservation activities. The program has been highly successful, with over 1.2 million hectares of forest protected since its implementation in 1997.

   The PES program has had a significant impact on forest conservation in Costa Rica, helping to reduce deforestation rates from 4% in the 1980s to less than 1% in the early 2000s. Additionally, the program has provided economic benefits to rural communities, creating jobs in the forestry and conservation sectors and promoting sustainable tourism (UNFCCC, 2023).

2. China's Giant Panda Conservation Program

   China's giant panda conservation program is a nature-based solution that has helped to protect and restore critical habitat for the endangered giant panda. The program involves the restoration of degraded forests and the creation of wildlife corridors to connect isolated panda populations.

   The program has had a significant impact on the conservation of giant pandas, with the population increasing from just over 1,000 in the 1970s to over 1,800 today. Additionally, the program has promoted sustainable tourism, providing economic benefits to local communities (Hua Xia, 2023).

3. The US Great Lakes Restoration Initiative

   In the United States, the Great Lakes Restoration Initiative is a nature-based solution that aims to restore and protect the Great Lakes ecosystem, including its forests, wetlands, and coastal habitats. The program involves a range of activities, including the restoration of degraded wetlands, the control of invasive species, and the reduction of nutrient pollution.

   The program has had a significant impact on the Great Lakes ecosystem, helping to reduce the harmful algal blooms that have plagued the region in recent years. Additionally, the program has provided economic benefits to local communities, promoting tourism and creating jobs in the conservation and restoration sectors (NOAA Fisheries, 2024).

4. Brazil's Forest Code

   Brazil's Forest Code is a nature-based solution that regulates the use and protection of forests in the country. The code requires landowners to maintain a certain percentage of their land as forest and establishes protections for sensitive areas such as riverbanks and hilltops.

   The Forest Code has had a significant impact on forest conservation in Brazil, helping to reduce deforestation rates in the Amazon region. Additionally, the code has provided economic benefits to rural communities, promoting sustainable agriculture practices and creating jobs in the forestry and conservation sectors. However, enforcement of the code has been challenging, and there have been concerns about the impact of recent changes to the code that have weakened some of its protections (Chiavari & Leme Lopes, 2015).

Further resources

1. Ceballos, Gerardo, and Paul R. Ehrlich. "The Misunderstood Sixth Mass Extinction." *Science* 360, no. 6393 (June 2018): 1080–1081.
2. IPBES. *Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Edited by S. Díaz, J. Settele, E. S. Brondízio, H. T. Ngo, M. Guèze, J. Agard, A. Arneth et al. Bonn, Germany: IPBES Secretariat, 25 Nov. 2019.
3. IUCN (International Union for Conservation of Nature) (website).

Issue 3: The sudden death of forests from infectious diseases is a major concern in the management and conservation of forests worldwide

Background

Infectious diseases can impact various tree species, including both conifers and broad-leaved trees, and the severity of the disease can vary widely depending on the species and environmental conditions. Infectious diseases in forests can be caused by a variety of pathogens, including fungi, bacteria, viruses, and other microorganisms. These pathogens can be spread by various means, such as through soil, water, insects, or other vectors.

When a tree is infected with an infectious disease, it can cause a range of symptoms, including wilting, yellowing, defoliation, and dieback of branches or the entire tree. In severe cases, the disease can cause sudden death of the tree, leading to significant impacts on forest structure, biodiversity, and ecosystem functioning.

The impacts of sudden death of forests from infectious diseases can be particularly significant in managed forests, where trees may be planted in monocultures or in high-density stands, making them more vulnerable to disease outbreaks. In addition, climate change is exacerbating the problem, as changes in temperature and precipitation patterns can increase the spread and severity of infectious diseases.

Recommendations

1. **Support all measures to prevent damage to forests caused by disease and infestations.** Support all measures to prevent, manage, and control the sudden death of forests from infectious diseases. Such measures include forest monitoring, quarantine and sanitation measures, use of disease-resistant tree species, and the development of effective treatments and management strategies. It's important to address this issue to protect forest ecosystems and the many ecological, economic, and social benefits they provide. Some specific measures are detailed in the following recommendations.
2. **Reduce unintended and intended transport of vegetative particles and soil.** Wash and disinfect shoes, tires, and anything that can transport vegetative particles and dirt.
3. **Use local firewood.** If using firewood, Don't move firewood—buy it where you burn it. Do not bring oak, fir, redwood, madrone, or tanoak outside of the area of origin unless they are certified to be free of *Phytophthora ramorum*. This would limit the spread of this pathogen (U.S. Department of Agriculture "Phytophthora Ramorum;" Schadel et al., 2020).
4. **Share information about Sudden Oak Death (SOD).** Spread the word about SOD, especially to those who engage in hiking, biking, and driving in and out of infected areas (NPS, "Sudden Oak Death").
5. **Engage stakeholders and remember the importance of oaks**. In addition to being a part of our cultural heritage, they are a keystone species in our ecological communities. Whole ecosystems of plants, animals, and fungi are dependent on the survival of our oaks (NPS, "Sudden Oak Death").

Case studies

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The state of California and the USDA (with the help of the Department of Homeland Security and the US Customs and Border Protection) are vigilant to limit the influx of infection vectors. Dutch elm disease, which affects species in the genera *Ulmus* and *Zelkova,* was a major challenge in northeastern North America (US/Canada) more than 40 years ago. Another pest is the spruce budworm.

1. Budworm

   "Budworm outbreaks can have significant economic impacts on the forestry *industry. As a result, the eastern spruce budworm is considered one of the most destructive forest pests in North America, and various methods of control are utilized. However, the species is also ecologically important, and several bird species are specialized on feeding on budworms during the breeding season."* (Schadel et al., 2020; Wikipedia, "Choristoneura fumiferana")

2. Asian Citrus Psyllid

   Citrus trees are also victims of Asian Citrus Psyllid (ACP), which can spread very fast from infected trees to healthy ones by the psyllid (USDA, 2024).

3. Dutch Elm Disease

   Dutch elm disease is caused by a fungus and affects elm trees. It was first identified in the Netherlands in the early 1900s and has since spread throughout Europe and North America. The disease is spread by bark beetles and can kill a tree within one to three years of infection. It has had a significant impact on elm tree populations, particularly in urban areas (Potter et al, 1966).

4. Chestnut Blight

   Chestnut blight is caused by a fungus and affects American chestnut trees. The disease was introduced to North America in the late 1800s and has since spread throughout the range of the American chestnut. The fungus infects the bark of the tree and can kill a tree within a few years of infection. The loss of American chestnut trees has had a significant impact on forest ecosystems and the many ecological, economic, and social benefits they provide (Rigling, 2018).

   Ash Dieback

5. Ash dieback is caused by a fungus and affects ash trees. The disease was first identified in Poland in the early 1990s and has since spread throughout Europe. The disease is spread by wind-borne spores and can cause significant damage to ash tree populations. In some areas, up to 90% of ash trees have been killed by the disease (Klesse et al., 2021).

Further resources

1. U.S. Code of Federal Regulations (CFR) 2022 § 301.92-2. *Restricted, Regulated, and Associated Articles; Lists of Proven Hosts and Associated Plant Taxa*. Title 7, Subtitle B, Chapter III, Part 301, Subpart X. Last amended May 2023.

Issue 4: Global reforestation potential has a large and cost-effective mitigation potential when done right

Background

"Forests and natural carbon sequestration are important climate change mitigation strategies with a biophysical mitigation potential of 5,380 MtCO2 per year on average until 2050" (IPCC, 2019), yet "forestry is a large industry and the causes of deforestation are mostly economically driven" (Steinweig, 2016), which means the future of our forests are currently dependent on exponential financial growth versus ecosystem health.

Forests are a critical part of the global carbon cycle, sequestering large amounts of carbon dioxide (CO_2) from the atmosphere through photosynthesis and storing it in biomass and soil. The global amount of carbon stored in forests is estimated to be approximately 638 billion metric tons, equivalent to around 2,340 billion MtCO2. The amount of carbon stored in forests varies depending on several factors, including the species of trees, their age and size, the location of the forests, and the management practices used. Tropical rainforests are some of the most carbon-dense forests, with an estimated 170 metric tons of carbon per hectare, while temperate and boreal forests typically store less carbon per hectare. "The causes of deforestation are mostly economically driven: expansion of commercial or subsistence agriculture, logging, fuelwood collection, or livestock grazing" (WWF, 2018).

On average, a mature tree can absorb around 22 kilograms of CO_2 per year, but this can vary widely depending on the tree species, size, age, and environmental conditions such as temperature, light, and water availability. Some studies have suggested that fast-growing tree species such as eucalyptus or hybrid poplar can absorb up to 48 kilograms of CO_2 per year per tree, while slower-growing species such as oak or pine may absorb less, around 15 kilograms of CO_2 per year. Generally, younger trees absorb more carbon than older trees, and trees in areas with higher rainfall and more sunlight tend to absorb more carbon than trees in drier areas (Collins, 2021).

The mitigation potential of reversing the deterioration of nature is large.

"Every year, the ocean absorbs about 30% of human-made carbon emissions, and terrestrial ecosystems absorb slightly less. The rest of our emissions enter the atmosphere. Over the years, this has caused the accumulation of approximately 300 Gt of excess carbon in the atmosphere." One "study finds an additional 0.9 billion hectares of forests could capture approximately 205 Gt carbon," that is, "two-thirds of the total human-made carbon emissions currently in the atmosphere" (Bastin et al., 2019).

"To counteract the economic incentives, payments for ecosystem services (Wunder, 2007) are increasingly provided (Donofrio et al., 2019) to forest-conserving or forest-restoring landowners by international stakeholders—for example, through the governmental UN-REDD program (Gibbs et al., 2007) or the commercial voluntary carbon market (Donofrio et al., 2019; Santamaria et al., 2020). Money from carbon offsets can provide vital financial support for projects seeking to protect and restore some of the most beautiful and threatened ecosystems around the world. Given that nature-based solutions can make a significant contribution to the climate mitigation needed to stabilize global heating, a functioning finance channel will be important for climate change progress, particularly for developing countries. However, so far only 2% of all global climate finance has been invested in nature-based solutions.

Recommendations

1. **Utilize UN Sustainable Development Goals (SDGs) and environmental, social, and corporate governance (ESG) metrics demonstrating "triple bottom line" metrics of success for society and business that prioritize planet and people before or in conjunction with profit to help ensure long-term health of our forests and those organizations that practice genuine sustainable business practices.**
2. **"To avoid catastrophic climate change, cut GHG emissions quickly and drastically, and reduce the excess GHG levels already in the atmosphere.** Achieving this will require many solutions. Restored trees will accumulate carbon slowly over the rest of this century and beyond. Like many climate change solutions, this is a long-term vision, which highlights the urgent need for action now" (ETHzürich. "Tree Restoration Potential, Q&A). Planting trees is not a silver bullet for climate change but can help. "Significant cuts to current emissions are still essential" and urgent (ETHzürich, "Tree Restoration Potential, Q&A.").
3. **Governments should implement policies that provide financial incentives for companies and individuals to invest in forest conservation and reforestation efforts.** This could include tax credits for reforestation projects, subsidies for sustainable forest management practices, and funding for research into new methods of carbon sequestration.
4. **Corporations should take a leadership role in promoting sustainable forest management practices and investing in reforestation efforts.** This should include setting targets for reducing deforestation in their supply chains, investing in sustainable agroforestry practices, and supporting conservation efforts through corporate social responsibility programs.
5. **Individuals should support reforestation efforts by donating to organizations that plant trees or support sustainable forest management practices.** They can also make changes in their own lives, such as reducing paper consumption or supporting sustainable forestry products.
6. **Policy makers must implement policies to promote sustainable land-use practices, such as incentivizing farmers to adopt agroforestry practices that integrate trees into agricultural landscapes.** This can increase carbon sequestration and biodiversity while also supporting rural livelihoods.
7. **Governments and corporations should work together to address the root causes of deforestation, such as the expansion of agricultural land and the demand for products like palm oil and soy.** This could include measures such as improving land-use planning, promoting sustainable agriculture, and supporting the development of alternative livelihoods for rural communities.

Case studies

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1. The REDD+ Program in Brazil

   The REDD+ program in Brazil has been successful in reducing deforestation rates in the Brazilian Amazon. According to a study by the Center for Global Development, the program led to a 70% reduction in deforestation in the Amazon between 2005 and 2012, which avoided the emission of approximately 1.2 billion tons of CO_2. The program also helped protect an estimated 60 million hectares of forest, which is equivalent to the size of France. (Fraser, 2023)

2. The Sustainable Agriculture and Forests Program in Indonesia

   The Sustainable Agriculture and Forests program in Indonesia has helped reduce deforestation rates while also providing economic opportunities for farmers and improving food security. According to a report by the World Resources Institute, the program has helped protect an estimated 5.5 million hectares of forest, which is equivalent to the size of Costa Rica. The program has also helped reduce greenhouse gas emissions by an estimated 0.4 billion tons of CO_2. (Global Waters, 2022)

3. The Forest Stewardship Council (FSC)

   The Forest Stewardship Council is an international organization that promotes sustainable forest management practices. According to a study by the University of Wisconsin-Madison, FSC-certified forests store an average of 6.7 metric tons of CO_2 per hectare per year, which is 37% more than noncertified forests. The study also found that FSC-certified forests have higher biodiversity and support local communities. (Forest Eco Certification)

4. The Green Belt Movement in Kenya

   The Green Belt Movement is a grassroots organization that promotes reforestation and community empowerment in Kenya. Since its founding in 1977, the organization has helped plant over 51 million trees and has provided economic opportunities to over 30,000 women through its tree-planting initiatives. According to a study by the University of Oxford, the trees planted by the Green Belt Movement have sequestered an estimated 2.5 million metric tons of CO_2, which is equivalent to taking more than 500,000 cars off the road for a year. (Green Belt Movement)

5. The Bonn Challenge

   The Bonn Challenge is a global effort to restore 150 million hectares of degraded and deforested land by 2020 and 350 million hectares by 2030. The initiative is led by the International Union for Conservation of Nature (IUCN) and the German government, and it has been endorsed by over 50 countries. According to a report by the IUCN, if the Bonn Challenge is successful, it could sequester up to 1.7 billion tons of CO_2 per year by 2030, which is equivalent to the annual emissions of India. (Caya, 2016)

Further resources

1. IPBES. *Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Edited by S. Díaz, J. Settele, E. S. Brondízio, H. T. Ngo, M. Guèze, J. Agard, A. Arneth et al. Bonn, Germany: IPBES Secretariat, 25 Nov. 2019.

Issue 5: Monitoring, verification, and reporting of nature-based solutions is capital- and labor-intensive

Background

> *"The certification process for forest carbon offsetting projects is capital- and labor-intensive, especially due to the high cost of manual" measurement and "monitoring), reporting, and verification (MRV) of the forest carbon stock."* (Reiersen et al., 2024)

> *"For the last 20 years, major conservation efforts have been underway to mitigate and safeguard against these losses. One of the global financing strategies is carbon offsets."* (Blaufelder et al, 2021)

> *"Initially, it started as the Clean Development Mechanism (CDM) under the Kyoto Protocol, allowing governments and business organizations from industrialized countries to invest in forestry in developing countries by buying carbon credits to offset industrialized emissions (FAO, 2020). Several other independent bodies have later developed official standards for verifying and certifying carbon offsetting projects, such as the Gold Standard (GS) and the Verified Carbon Standard (VERRA). The certification process for forest carbon offset projects is capital- and labor-intensive, especially due to the high cost of manual MRV" of the forest carbon stock."* (Reiersen et al., 2024)

According to a report by the Food and Agriculture Organization (FAO) and the United Nations Development Programme (UNDP), an estimated $80 billion to $100 billion per year is needed to halve deforestation rates by 2030 and restore degraded forests. This investment is needed to support activities such as strengthening forest governance, providing incentives for sustainable land use, and scaling up restoration efforts.

"The carbon offsetting market is rapidly increasing and expected to grow by a factor of 100 until 2050 due to high demand and available capital" (Blaufelder et al., 2021). However, the main obstacle is "the limited supply of offsetting projects as forest owners lack upfront capital and market access" (Kamukama, 2022; (Reiersen et al., 2024). "Current methods for…MRV of the landowner-provided forest ecosystem services are either based on 1) on-ground inspection, which is…expensive (US $20,000 to US $30,000)," can be "delayed (up to two years)," or be "corruptible, and biased" (Foss, 2013); 2) satellite-based data, which is lower-cost but may be limited to the binary verification of forest/no-forest cover (Hanan et al., 2020); or 3) drone-based data collection. Further, forests are complex ecosystems with multiple layers and components, including different tree species, understory vegetation, and soil microorganisms. Monitoring and reporting on these components is difficult, particularly if they are not directly visible or easily measurable (Reiersen et al., 2024).

Recommendations

1. **Invest in innovation of technology. Invest in technology innovation such as satellite monitoring, drone analysis, and automated on-ground data collection that allows for low-cost MRV. Develop new technologies for MRV:** The use of new technologies such as remote sensing and machine learning (ML) can help reduce the cost and time required for MRV. For example, light detection and ranging (lidar) technology can be used to measure the height and density of trees, which can be used to estimate carbon stock. ML algorithms can be used to analyze this data and provide accurate estimates of carbon sequestration.
2. **Carefully consider which technology addresses the goal(s) effectively.** Acknowledge that technology is not a silver bullet and seek to accelerate those applications that correctly address the barriers to scale in the use of technology for environmental good:
    a. **Increase data compatibility, making more geospatial and in situ data accessible for model training–effective use of ML is hindered by a lack of accessible data.**
    b. **Harness AI and ML to create new—and to scale existing (and promising)—granular climate models.**
    c. **Access computing resources for the purpose of training AI models, especially for developing countries.**
    d. **Develop technical expertise and skills to integrate data and computing resources, tools, and models to produce insights.**
    e. **Leverage domain expertise and management capabilities to turn AI-generated climate insights into policy-making decisions.**
3. **Build capacity.** Local communities need the technical skills and knowledge to effectively monitor and report on forest carbon stocks and emissions. Capacity-building programs can help to provide training and support for community members, including on the use of MRV technologies and data analysis.
4. **Provide local control.** Providing local communities with ownership and control over MRV technology can help to build trust and accountability. This can include developing community-led MRV systems and providing access to data and information on forest carbon stocks and emissions.
5. **Support collaboration.** Collaboration between local communities, governments, and the private sector can help to ensure that MRV systems are integrated into broader forest conservation and management strategies. This should include developing partnerships and alliances to share data and knowledge, as well as leveraging funding and technical support.
6. **Encourage collaboration among project developers.** Encouraging project developers to collaborate and share information on MRV can help reduce duplication of effort and facilitate the development of best practices. For example, the Forest Carbon Partnership Facility (FCPF) has established a knowledge-sharing platform to encourage collaboration among project developers and to share information on MRV best practices.
7. **Provide incentives.** Providing financial and nonfinancial incentives for local communities to participate in MRV can help to promote uptake and sustainability. This should include providing payments for verified emissions reductions or other benefits such as improved forest governance, biodiversity conservation, or livelihood opportunities.

8. **Implement standardized MRV protocols.** Developing standardized MRV protocols can help reduce the time and cost required for certification by streamlining the process and making it more transparent. For example, the Verified Carbon Standard (VCS) has developed a standardized methodology for measuring forest carbon stock and determining the additionality of forest carbon offsetting projects. Another example is work under development of IEEE P7802, Standard for Measurement and Verification of Reduction of Greenhouse Gases for Climate Action Projects and Solutions (IEEE SA, IEEE P7802).
9. **Provide financing and technical support.** Providing financing and technical support to project developers, particularly in developing countries, can help overcome barriers to entry and increase access to the resources needed for MRV. For example, the World Bank's BioCarbon Fund provides financing and technical assistance to support forest carbon offsetting projects in developing countries.

Case studies

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1. The Implementation of the Verified Carbon Standard (VCS) in the Rimba Raya Biodiversity Reserve Project in Indonesia

   The Rimba Raya Biodiversity Reserve project in Indonesia was the first REDD+ project to receive VCS certification. The project involves the conservation of more than 64,000 hectares of tropical forest, which has sequestered an estimated 20 million metric tons of CO_2. The use of standardized MRV protocols under the VCS certification process helped streamline the MRV process and reduce the cost of certification while also increasing the credibility and transparency of the project (InfiniteEARTH).
2. The Collaboration Among Project Developers in the Community-Based REDD+ Project in Nepal

   The Community-Based REDD+ project in Nepal is a community-led initiative that aims to conserve and restore forests while also providing economic opportunities to local communities. The project involves the collaboration of several community groups, nongovernmental organizations (NGOs), and government agencies who share information and resources on MRV best practices. This collaboration has helped reduce duplication of effort and facilitate the development of cost-effective MRV approaches (ANSAB, 2013).
3. The Provision of Financing and Technical Support in the BioCarbon Fund Initiative for Sustainable Forest Landscapes (ISFL)

   The BioCarbon Fund ISFL is a partnership between the World Bank and several donor countries, providing financing and technical assistance to support forest conservation and restoration in developing countries. The initiative has provided financing and technical support to several forest carbon offsetting projects, including in Brazil, Indonesia, and Ethiopia. This support has helped overcome barriers to entry and increase access to the resources needed for MRV (Initiative for Sustainable Forest Landscapes, "BioCarbon Fund")

4. The Provision of Policy Support in the California Compliance Offset Program

   The California Compliance Offset Program provides incentives for companies to invest in forest carbon offsetting projects, such as the Improved Forest Management project in the Sierra Nevada mountains. This project involves the sustainable management of more than 22,000 hectares of forest, sequestering an estimated 2 million metric tons of CO_2. The policy support provided by the California Air Resources Board has helped increase the demand for legitimate carbon offsetting projects while also creating a more favorable environment for investment in MRV technology and best practices (California Air Resource Board, “Compliance Offset Program”).

Further resources

1. Brown, Sandra, and Louis R. Iverson. “Biomass Estimates for Tropical Forest.” *World Resource Review* 4, no. 3 (1992): 366–383.

Issue 6: Nature-based carbon offsets currently lack trust and integrity standards, harming the world's climate

Background

Forest carbon offsets and methodologies are prone to errors and deliberate systematic over-accounting, undermining trust in offsets while providing large industries an opportunity to greenwash.

The forest protection carbon offsetting market is used by major airlines for claims of carbon-neutral flying and by major fossil fuel companies to showcase their climate ambition. However, it faces a significant credibility problem and there are warnings that the system may not be fit for purpose.

One of the main challenges with forest carbon offsets is the complexity of measuring and verifying the carbon benefits of these projects. Forests are dynamic ecosystems with multiple layers and components, making it difficult to accurately quantify carbon stocks and emissions. In addition, natural disturbances such as wildfires and pests can have a significant impact on forest carbon dynamics, making it challenging to attribute carbon benefits to specific conservation or restoration activities.

> *"Recent research investigations (Badgley et al., 2022) have shown that the current manual forest carbon stock practices systematically overestimate forestry carbon offsetting projects with up to 29% of the offsets analyzed, totaling up to 30 million tCO2e (metric tons of CO_2 equivalents) and worth approximately $410 million."*
> (Reiersen et al., 2024)

Overestimation can occur when project developers inflate the carbon benefits of their projects through practices such as double counting or using inaccurate baseline scenarios. This can lead to an overestimation of the carbon benefits of the project, which can undermine the effectiveness of the offset and erode trust in the integrity of the carbon market.

Recommendations

1. **Create trust through radical transparency**. **Open up methodologies, baselines, algorithms, and models transparently for independent audits to create trust.** Increasing transparency and accountability in the forest carbon offsetting process can help reduce the risk of errors and deliberate over-accounting. This should include requiring project developers to provide detailed documentation of their MRV processes, as well as establishing third-party verification of carbon stock estimates and project additionality.
2. **Implement a blockchain-based registry for forest carbon offsets.** It should be possible to reduce the risk of errors and deliberate over-accounting by providing a transparent and traceable system for monitoring and reporting on carbon benefits. This is expected to help increase trust in the integrity of forest carbon offsets and reduce the opportunity for large industries to engage in greenwashing by investing in low-quality offsets that do not deliver real emissions reductions.

3. **Create a tamper-proof record of project data, including project design, monitoring and verification data, and transaction records.** This can help to reduce the risk of fraud and improve the accuracy and credibility of forest carbon offsets.
4. **Invest in codesigning MRV systems with local communities.** This approach can help ensure that the technology is appropriate and effective for the local context. This process should include involving local stakeholders in the design of monitoring protocols, selecting appropriate technologies, and interpreting and communicating data.
5. **Strengthen verification protocols.** Strengthening verification protocols for forest carbon offsetting projects can help reduce the risk of errors and over-accounting. This should include requiring project developers to use standardized methodologies for MRV and establishing minimum requirements for third-party verification.
6. **Establish penalties for noncompliance.** Establishing penalties for noncompliance with forest carbon offsetting standards and protocols should help deter deliberate over-accounting and other forms of misconduct. This can include fines and sanctions for project developers found to be in violation of established standards and protocols.
7. **Establish clear standards and protocols for measurement and audit.** Establishing clear standards and protocols for measurement and audit can help prevent over-accounting by providing a consistent and transparent framework for carbon accounting. These standards and protocols should be based on best practices and should be subject to review and revision as necessary.
8. **Conduct frequent and random spot checks.** Conducting frequent and random spot checks of measurements and audits can help detect any over-accounting or other irregularities that may occur. These spot checks should be conducted by independent third-party auditors and should be a requirement for all forest carbon offsetting projects.
9. **Encourage disclosure and reporting of over-accounting.** Encouraging project developers and auditors to disclose any instances of over-accounting or other irregularities can help increase transparency and prevent future instances of misconduct. This can include requiring regular reporting of carbon accounting and making this information publicly available.

Case studies

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1. For Independent Third-Party Auditors

   The California Air Resources Board (CARB) Compliance Offset Protocol requires the use of independent third-party verifiers to help ensure the accuracy and reliability of forest carbon offsetting projects. The verifiers must be accredited by the American National Standards Institute (ANSI) and meet other qualification requirements. The use of independent third-party auditors helps prevent over-accounting by ensuring that carbon stock estimates are independently verified.

2. For Clear Standards and Protocols for Measurement and Audit

   The Forest Stewardship Council (FSC) has established clear standards and protocols for forest carbon offsetting, including requirements for MRV and third-party verification. These standards and protocols are based on best practices and are subject to regular review and revision. The use of clear standards and protocols helps prevent over-accounting by providing a consistent and transparent framework for carbon accounting.

3. For Frequent and Random Spot Checks

   The Verified Carbon Standard (VCS) requires project developers to conduct frequent and random spot checks of their MRV processes for accuracy and reliability of carbon stock estimates. The VCS also requires independent third-party verification of carbon stock estimates to confirm that these spot checks are conducted properly. The use of frequent and random spot checks helps prevent over-accounting by detecting any irregularities that may occur.

4. For Blockchain Technology

   HBAR Foundation, the foundation behind Hedera Hashgraph, has created the Guardian, a tool for recording digital MRV. The Guardian is an open source blockchain library to support registration for carbon offsetting. It is developing a platform that provides secure and transparent carbon accounting. The use of blockchain technology helps prevent over-accounting by providing a decentralized and transparent record of carbon transactions.

5. For Disclosure and Reporting of Over-Accounting

   The Rainforest Alliance, a nonprofit organization that works to promote sustainable forestry, requires project developers to disclose any instances of over-accounting or other irregularities as part of its certification process. This information is publicly available on the Rainforest Alliance website. The use of disclosure and reporting helps prevent over-accounting by increasing transparency and accountability.

Issue 7: Individual tree accounting is almost nonexistent, making various techniques such as selective logging and selection cutting difficult to execute, monitor, and verify

Background

Individual tree accounting refers to the practice of tracking the growth, mortality, and carbon sequestration of individual trees in a forest. This practice is important for understanding the overall carbon balance of the forest, as well as for informing forest management practices such as selective logging and selection cutting. However, individual tree accounting is often difficult to implement, particularly in large-scale forest management operations, due to the high cost and technical complexity of monitoring and measuring individual trees. No individual identification exists for trees to track their existence, so when trees are cut and hauled away, there is no way for law enforcement to record their loss. Trees do not have serial numbers.

As a result, many forest management practices, such as selective logging and selection cutting, are often carried out without accurate information on the carbon sequestration potential of individual trees. This can lead to suboptimal forest management decisions and can undermine efforts to promote sustainable forestry practices that balance economic, social, and environmental considerations. Additionally, the lack of individual tree accounting can make it difficult to accurately estimate the carbon sequestration potential of a forest, which can in turn affect the ability of forest carbon offsetting projects to generate credits.

Anecdotally, there is no specific accounting for how many trees are being lost and no legal process to account for losses even on privately owned land. On the other hand, cities like Mountain View, CA, tout their canopy coverage by promoting that the city has the best canopy foliage by counting the number of shrubs and young trees planted for every mature tree cut. Sometimes trees as old as 200 years are cut and replaced with three or four smaller shrubs that will take another 30 to 40 years to grow to just a few feet tall.

Recommendations

1. **Tag and track the history of individual trees.** There are high-end solutions like geospatial mapping that feeds into ML models to assess the number of trees. Aerial views of the past can be compared to those of the present. Most cities have extensive paper trails for every process, so the number of trees removed can be tracked by their process paperwork alone—all tallied on good old spreadsheets. It requires the public to demand transparency, and that is the issue: making the public care enough to demand transparency from their governments. Simple QR codes and geotagging have worked well in many countries to track trees. Tagging for existing trees and new ones planted should be more common.
2. **Develop more advanced and sophisticated monitoring techniques that can track the carbon stored in individual trees within a forest ecosystem.** This can and should include using remote sensing technologies such as lidar to map the structure and composition of the forest, as well as developing ground-based monitoring techniques that can track the growth and health of individual trees over time.

3. **Develop genetic barcoding.** Develop and implement genetic barcoding techniques for individual trees in a forest. This can involve using DNA sequencing to create a unique genetic barcode for each tree, which can be used to track its growth, mortality, and carbon sequestration over time. The genetic barcodes can be linked to other data on the tree, such as its size, location, and age, as well as data on the surrounding environment, such as soil type and moisture levels.
4. **Use genetic barcoding.** By using genetic barcoding, forest managers can accurately track the carbon sequestration potential of individual trees, allowing for more precise forest management decisions. This can include selectively harvesting trees based on their carbon sequestration potential or planting new trees with specific genetic traits that promote carbon sequestration. Additionally, genetic barcoding can provide important data for forest carbon offsetting projects, which require accurate measurements of carbon stock.
5. **Deploy and utilize sensor-equipped tree robot.** Develop and implement tree-climbing robots equipped with lidar and other sensors to map out the structure of individual trees before cutting. These robots can be programmed to climb trees and collect data on their size, shape, and biomass, as well as to identify potential hazards such as weak or dead branches. The lidar and other sensors can provide high-resolution 3D scans of the tree's structure, allowing for accurate and detailed measurements of individual branches and foliage.
6. **Utilize the data collected by the tree-climbing robots to inform forest management decisions, such as the selective removal of specific branches or trees.** This can help reduce the risk of accidental damage to surrounding trees or to the environment, while also ensuring that the most valuable timber is harvested. Additionally, the data collected by the robots can be used to improve forest carbon stock estimates, which can be used to generate carbon credits for forest carbon offsetting projects.
7. **Consider deploying block chain technology to safe-guard and share data.** Blockchain technology has a key advantage due to its ability to provide a tamper-resistant and decentralized system for storing and sharing data. This can be particularly useful for tracking changes in forest ecosystems, as it can provide a transparent and verifiable record of individual tree growth, carbon sequestration, and other key metrics.

Case studies

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1. Tree-Climbing Robots

   The startup Treebot[1], based in Switzerland, has developed a tree-climbing robot equipped with sensors and cameras that can climb trees up to 70 meters tall. The robot can collect data on the tree's structure, including its size, shape, and biomass, as well as identifying potential hazards such as weak or dead branches.

[1]This information is given as an example for the convenience of users of this document and does not constitute an endorsement by the IEEE. Similar or equivalent products and services may also be available from other companies and organizations.

2. Genetic Barcoding for Trees

   Researchers at the University of British Columbia, Canada, have developed a genetic barcode for individual trees, allowing them to track the carbon sequestration potential of each tree over time. The genetic barcodes can be used to inform forest management decisions, such as selectively harvesting trees with high carbon sequestration potential.

3. Remote Sensing Technologies

   The Global Ecosystem Dynamics Investigation (GEDI) satellite from the National Aeronautics and Space Administration (NASA) uses lidar technology to provide detailed information on the structure and biomass of individual trees in forests around the world. This data can be used to inform forest management decisions and improve forest carbon stock estimates.

4. Drones for Aerial Surveys

   The startup DroneSeed[2], based in Seattle, WA, uses drones equipped with lidar and multispectral cameras to map out forest ecosystems and identify areas that require reforestation. The drones can also plant new trees using a precision planting system.

5. Mobile Apps for Data Collection

   The Rainforest Connection[3], a nonprofit organization that works to prevent illegal deforestation, has developed a mobile app that uses ML to detect sounds of illegal logging activities in real time. The app also collects data on forest biodiversity, helping to inform forest management decisions.

6. Satellite Mapping

   Earth observation with machine learning-based methods plays a crucial role in environmental and climate sciences. Being able to continuously monitor and report changes is an important tool for decision-makers to address urgent challenges in climate change mitigation and adaptation, especially for forestry where land-use change is one of the key factors to understand. Earth observation data is stored in the petabyte scales. Public institutional data such as the European Space Agency's Sentinel-1 synthetic aperture radar data and Sentinel-2 optical images produce four petabytes of data. Private providers such as Maxar have reportedly stored more than 110 petabytes in its image library since 2000, adding up to 80 terabytes of satellite data per day. Leveraging this data, researchers have developed global maps on tree cover loss and gains (Hansen et al., 2011), reforestation potential (Bastin et al., 2019), and biodiversity richness (Jetz et al., 2012).

7. Digital Twins

   Creating digital replicas that mirror the existence and dynamics of physical objects, processes, assets, or arrangements is known as the creation of *digital t*wins. Using advances in satellite, aerial, and on-ground sensing technologies, realistic records of land cover, forest type, biomass, and canopy height can be created. The ever-growing spatiotemporal data records are used to improve the accuracy of digital twins, namely climate and land surface models, such that it can forecast the state and health of forests. Forest digital twins could be advanced toward mapping ecosystem health, carbon content, and biodiversity or the rapid exploration of climate policy impacts, visualizing future scenarios. Advances in digital twins have historically been applied extensively in architecture, BEAM modeling, and simulation design. For the sake of the IEEE Planet Positive 2030 application, focusing on data

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curation, collection, sensing, mapping, and simulating challenging forest landscapes and the interior canopy of rainforests is proposed.

8. Decentralized Ledgers and On-Chain Representation

   Decentralized ledger technology as a whole is oriented towards the use of an open and public decentralized ledger to create a permanent record keeping of account. This is for the sake of economic support, as well as representation of digital environmental attributes such as carbon removal credits and hectares of land preservation.

9. AI NLP Speech Partners

   Drawing from the existing advancements in artificial intelligence for natural language processing (NLP), there are opportunities to make an AI chatbot that can persuasively and humanely interact with external audiences, bringing an emphatic "voice" and "character" to an otherwise amorphous concept of trees and hectares. Key tools and advances in AI can be used to represent and design at scale a mass market-facing awareness-building tool, for example, by allowing the AI to actively engage with conversations on social media platforms.

Further resources

1. Nix, Steve. "3 Ways Your Trees Can Be Stolen." ThoughtCo. Last updated 13 Aug. 2019.
2. Njambi, Rose. "Tackling Deforestation in India: Why You Need Satellite Data." UP42, 20 Sept. 2021.
3. Noack, Mark. **"**Is Mountain View Losing Its Trees? New City Data Still Leaves Question Up in the Air." *Mountain View Voice,* 1 July 2018.
4. Vyawahare, Malavika. "Tree-Planting Programs Turn to Tech Solutions to Track Effectiveness." *Mongabay*, 22 Nov. 2019.
5. Yao, Ling, Tang Liu, Jun Qin, Ning Lu, and Chengdu Zhou. "Tree Counting with High Spatial-Resolution Satellite Imagery Based on Deep Neural Networks." *Ecological Indicators* 125 (June 2021).

Issue 8: Despite the social media-driven push for corporate engagement on tree planting, numerous organizations have advocated that the process of tree and forestry protection is much more effective than that of virgin tree planting

Background

The key debate is between the merits of reforestation and the merits of preserving what we have available. Some simple analysis by EcoCart[4] shows:

- "Trees can take up to 10 years before they start absorbing more carbon dioxide than they emit."
- "Planting new trees requires more work."
- Planting new trees is expensive.
- Reforestation projects can be less sustainable, as it is uncertain whether "the newly planted forests will be capable of supporting animal, insect, and plant ecosystems as current forests actively do."

Recommendations

1. **Protect and save existing forests first**. Advocates from the World Wildlife Fund (WWF) acknowledge: "Planting trees is good. Saving existing forests is better. Protecting people and nature is best" (Stevenson, 2020).

   The mathematics behind forestry protection is much better than reforestation.

2. **Support thoughtful mass tree planting in addition to protecting existing forests.** Mass tree planting initiatives are a possibility but also require thoughtful planning and execution. Planting the wrong trees in the wrong place may reduce biodiversity, speed up extinctions, and reduce resiliency of ecosystems (Einhorn, 2022).

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Case studies

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1. GainForest[5]

   "GainForest is an open platform that empowers sustainable conservation efforts by unifying 1) accessible and automated monitoring, 2) auditable and decentralized payments, and 3) stakeholder engagement and user-focused token incentives into one system...Tracing the impact of a donor's individual donation is difficult, making it hard for them to develop a sense of ownership. GainForest NFTrees make payments to conservation organizations more tangible. They are unique digital assets that track the ownership of virtual sites of a conservation or restoration project using blockchain technology. Virtual sites correspond to a predefined land area within the project with possibly multiple plants." (GainForest Primer)

2. NFTree Tokens

   "NFTree tokens include unique artwork from local communities and Indigenous artists for each project. Each token links to a unique" monitoring "website…that provides geospatial and ecological information of the corresponding site, displaying recent drone and satellite data, current and potential tree cover," the existing "species of flora…and how much carbon is currently stored or could potentially be stored if the ecosystem was intact. The group of corresponding plants within an NFTree can change during its lifetime due to survival rates and active restoration efforts. NFTree holders can follow recent updates and progress on their respective conservation areas through the NFTree profile website," dynamic artwork, and data airdrops. "Investments raised from NFTrees are first parked in a decentralized fund. Payments are automatically released to conservation organizations after achieving specific milestones during the verifiable 'Proof-of-Care'" stage, which consists of automated digital MRV. (GainForest Primer)

[5] This information is given as an example for the convenience of users of this document and does not constitute an endorsement by the IEEE. Similar or equivalent products and services may also be available from other companies and organizations.

References

1. ANSAB. "Community-Based REDD+ Pilot Program in Nepal: Incentive for Climate Change Mitigation and Forest Conservation Measures." 21 March 2013.
2. Badgley, Grayson, Jeremy Freeman, Joseph J. Hamman, Barbara Haya, Anna T. Trugman, William R. L. Anderegg, and Danny Cullenward. "Systematic Over-Crediting in California's Forest Carbon Offsets Program." *Global Change Biology* 28, no. 4 (Feb. 2022).
3. Bastin, Jean-Francois, Yelena Finegold, Claude Garcia, Danilo Mollicone, Marcelo Rezende, Devin Routh, Constantin M. Zohner, et al. "The Global Tree Restoration Potential." *Science* 365, no. 6448 (July 2019): 76–79.
4. Blaufelder, Christopher, Cindy Levy, Peter Mannion, and Dickon Pinner. "A Blueprint for Scaling Voluntary Carbon Markets to Meet the Climate Challenge." McKinsey Sustainability, 29 Jan. 2021.
5. Brock, R.C., A. Arnell, W. Simonson et al. "Implementing Brazil's Forest Code: A Vital Contribution to Securing Forests and Conserving Biodiversity." *Biodiversity and Conservation* 30 (2021) 1621–1635.
6. California Air Resource Board. "Compliance Offset Program."
7. Canadell, J. G., and M. R. Raupach. "Managing Forests for Climate Change Mitigation." *Science* 320 (2008): 1456–1457.
8. Caya, Sandra. "Bonn Challenge Approaches Target to Restore 150 Million Hectares of Degraded Land." IUCN, 2016.
9. Chiavari, Joana and Cristina Leme Lopes. *Policy Brief---Brazil's New Forest Code, Part I: How to Navigate the Complexity*. Climate Policy Initiative, 2015.
10. Collins, Paul. "How Much CO2 Does a Tree Absorb?" Climate Consulting by Selectra, 2021.
11. Dao, David, Catherine Cang, Clement Fung, M. Zhang, Nick Pawlowski, R. Gonzales, Nick Beglinger, and Ce Zhang. "GainForest: Scaling Climate Finance for Forest Conservation using Interpretable Machine Learning on Satellite Imagery." International Conference on Machine Learning 2019.
12. Einhorn, Catrin. "Tree Planting is Blooming. Here's How That Could Help, or Harm, the Planet." *New York Times*, 14 Mar. 2022. Last updated 21 Mar. 2022.
13. Ehrlich, Gabriel, Donald Grimes, Michael McWilliams et al. "Socioeconomic Impacts of the Great Lakes Restoration Initiative." University of Michigan Research Seminar in Quantitative Economics. 30 Sept. 2018.
14. ETHzürich. The Crowther Lab (website).
15. ETHzürich. "Tree Restoration Potential, Q&A." The Crowther Lab.
16. Fearnside, Phillip. "Deforestation of the Brazilian Amazon." Oxford Research Encyclopedia of Environmental Science. 26 Sept. 2017.
17. Forest Eco Certification. "FSC Certification."
18. Foss, Mark. "The Challenge of Certifying Forest Ecosystem Services." *Forest News*, 2013.
19. Fraser, Barbara. "Following the REDD+ Money." CIFOR Forest News, 2023.
20. Global Waters. *Indonesian Forest and Climate Support Project (IFACS)*. 2022.
21. Green Belt Movement (website).

22. Hanan, Niall P., and Julius Y. Anchang. "Satellites Could Soon Map Every Tree on Earth." *Nature* 587 (2020).

23. Hua Xia, ed. "Update: China Establishes National Giant Panda Conservation, Research Center." Xinhua, 17 Nov. 2023.

24. Initiative for Sustainable Forest Landscapes. "BioCarbon Fund." World Bank.

25. IEEE Standards Association. *IEEE P7802, IEEE Draft Standard for Measurement and Verification of Reduction of Greenhouse Gases for Climate Action Projects and Solutions.*

26. IPCC, 2019. *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. Edited by P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, et al. In press.

27. IPCC. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. V. Masson-Delmotte, P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou, eds. Cambridge and New York: Cambridge University Press, 2021.

28. Jetz, Walter, Jana McPherson, and Robert Guralnick. "Integrating Biodiversity Distribution Knowledge: Toward a Global Map of Life." *Trends in Ecology & Evolution* 27 (2012): 151–9.

29. Kamukama, Marvin K. D. *Trees for Global Benefit Uganda: A Case Study on the Failures of Carbon Offsetting*. 2022.

30. Klesse, Stefan, Meinrad Abegg, Sven E. Hopf, Martin M. Gossner, Andreas Rigling, and Valentin Queloz. "Spread and Severity of Ash Dieback in Switzerland–Tree Characteristics and Landscape Features Explain Varying Mortality Probability." *Frontiers in Forrest and Global Change* 4 (Mar. 2021).

31. Krantzberg, Gail, Irena F. Creed, Kathryn B. Friedman, Katrina L. Laurent, John A. Jackson, Joel Brammeier, and Donald Scavia. "Community Engagement is Critical to Achieve a "Thriving and Prosperous" Future for the Great Lakes–St. Lawrence River Basin." *Journal of Great Lakes Research* (2014).

32. Nabuurs, G.J., O. Masera, K. Andrasko, P. Benitez-Ponce, R. Boer, M. Dutschke, E. Elsiddig, J. Ford-Robertson, P. Frumhoff, T. Karjalainen, O. Krankina, W.A. Kurz, M. Matsumoto, W. Oyhantcabal, N.H. Ravindranath, M.J. Sanz Sanchez, and X. Zhang. *Forestry. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer. Cambridge and New York: Cambridge University Press, 2007.

33. National Park Service (NPS). "Sudden Oak Death." Point Reyes, National Seashore, California.

34. NOAA Fisheries. Great Lakes Habitat Restoration (website). Last updated 10 Sept. 2024.

35. Potter, Clive, Tom Harwood, Jon Knight, and Isobel Tomlinson. "Learning from History, Predicting the Future: The UK Dutch Elm Disease Outbreak in Relation to Contemporary Tree Disease Threats." *Philosophical Transactions of the Royal Society B: Biological Sciences* 366, no. 1573 (July 2011): 1966–74.

36. Powell, William A., Andres E. Newhouse, and Vernon Coffey. "Developing Blight-Tolerant American Chestnut Trees." *Cold Spring Harbor Perspectives in Biology* 11, no. 7 (July 2019).

37. Reiersen, Gyri, David Dao, Björn Lütjens, Konstantin Klemmer, Kenza Amara, Attila Steinegger, Ce Zhang, and Xiaoxiang Zhu. "ReforesTree: A Dataset for Estimating Tropical Forest Carbon Stock with Deep Learning and Aerial Imagery." arXiv.org, 6 Mar. 2024.
38. Rigling, D., and S. Prospero. "Cryphonectria Parasitica—The Causal Agent of Chestnut Blight: Invasion History, Population Biology and Disease Control." *Mol Plant Pathol 19*, no. 1 (Jan. 2018): 7–20.
39. Riyou Tsujino, Takakazu Yumoto, Shumpei Kitamura, Ibrahim Djamaluddin, Dedy Darnaedi. "History of Forest Loss and Degradation in Indonesia." *Land Use Policy* 57 (2016): 335–347.
40. Saatchi, Sassan, Salvi Asefi-Najafabady, Yadvinder Malhi, Luiz E. O. C. Aragão, Liana O. Anderson, Ranga B. Myneni, and Ramakrishna Nemani. "Persistent Effects of a Severe Drought on Amazonian Forest Canopy."*PNAS* 110, no. 2 (24 Dec. 2012).
41. Sánchez-Azofeifa, G. A., A. Pfaff, J. A. Robalino, and J. P. Boomhower. "Costa Rica's Payment for Environmental Services Program: Intention, Implementation, and Impact." *Conservation Biology* 21, no. 5 (Oct. 2007) 1165–73.
42. Santamaria, Simona, David Dao, Björn Lütjens, and Ce Zhang. "TrueBranch: Metric Learning-based Verification of Forest Conservation Projects." Arxiv.org, 21 Apr. 2020.
43. Schadel, B. R., and W. Wesela. "APHIS List of Regulated Hosts and Plants Proven or Associated with Phytophthora Ramorum." *Pacific Northwest Pest Management Handbooks*. July 2020.
44. Steinweg, Tim, Barbara Kuepper, and Gabriedl Thoumi. *Economic Drivers of Deforestation: Sectors Exposed to Sustainability and Financial Risks*. Chain Reaction Research, Aug. 2016.
45. Stephens, Scott, Brandon Collins, Christopher Fettig, Mark Finney, Chad Hoffman, Eric Knapp, Malcolm North, Hugh Safford, and Rebecca Wayman. (2018). "Drought, Tree Mortality, and Wildfire in Forests Adapted to Frequent Fire." *BioScience* 68, no. 2 (Feb. 2018): 77–88.
46. Stevenson, Martha. "Sustainability Works." World Wildlife Fund, Transforming Business. 28 Apr. 2020.
47. Swaisgood, R. R., F. Wei, D. E. Wildt, A. J. Kouba, and Z. Zhang. "Giant Panda Conservation Science: How Far We Have Come." *Biology Letters* 6, no. 2 (23 Apr. 2010):143–145.
48. Tchatchou, B., D. J. Sonwa, S. Ifo, and A. M. Tiani. Deforestation and Forest Degradation in the Congo Basin: State of Knowledge, Current Causes and Perspectives: Occasional Paper 144. Bogor, Indonesia: CIFOR, 2015.
49. UN Climate Change, UNFCCC. "Payments for Environmental Services Program: Costa Rica." Climate Action, 2023 UN Global Climate Actions Awards.
50. UN Environment Programme (UNEP). *The Nature-Based Solutions for Climate Manifesto: Developed for the UN Climate Action Summit 2019*. 14 Aug. 2019.
51. U.S. Department of Agriculture (USDA). "Citrus Greening and Asian Citrus Psyllid." Plant Pests and Diseases, Citrus Diseases.
52. U.S. Department of Agriculture (USDA). "Phytophthora Ramorum." Animal and Plant Health Inspection Services.
53. Vallance, Patrick. "We've Overexploited the Planet, Now We Need to Change if We're to Survive." *The Guardian*, 8 Jul. 2022.

54. Van Noordwijk, Meine, Berla Laimonas, Minh Ha Hoang, Grace Villamor, and Thomas Yatich. "Principles for Fairness and Efficiency in Enhancing Environmental Services in Asia: Payments, Compensation, or Co-Investment?" *Ecology and Society* 15, no. 4 (2010).

55. World Wildlife Fund (WWF). "What are the Biggest Drivers of Tropical Deforestation?" WWF Magazine, 2018.

56. Wunder, Sven et al. "Payments for Environmental Services and the Poor: Concepts and Preliminary Evidence." *Environment and Development Economics* 10, no. 3 (2005).

57. Zhisong Yang, Xiaodong Gu, Yonggang Nie, Feng Huang, Yan Huang, Qiang Dai, Yibo Hu, Yi Yang, Xiao Zhou, Hemin Zhang, Xuyu Yang, and Fuwen Wei. "Reintroduction of the Giant Panda into the Wild: A Good Start Suggests a Bright Future." *Biological Conservation* 217 (2018): 181–186.

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