Digital Dividends

in Natural Resource Management

May 2020

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The CleanTech programme brokers partnerships across industries and sectors, creates best practices and develops a common narrative to support the transition to resilient, equitable and decarbonised societies. Digital technology, including mobile solutions, is uniquely positioned to provide effective tools for climate change mitigation and adaption, e-waste management, disaster response and environmental monitoring. At the same time, through our access to a member network of mobile operators, device manufacturers and equipment providers, the GSMA is well-placed to identify innovation, facilitate scale and lead the transition towards circularity in the digital economy's supply chain.

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Executive summary

Natural resource management (NRM) refers to the sustainable use and management of the planet's natural resources, including forests, watersheds, oceans, air and a diversity of plant and animal species.

These and other resources work together to produce the benefits and services on which human existence depends, such as the provision of food, medicine and timber, the regulation of our climate, the improvement of our water and air quality, and protection from natural hazards. They are also critical to our livelihoods and well-being: close to 1.6 billion people—over 25 per cent of the world's population—rely on forest resources for their livelihoods,[1] and another three billion depend on marine and coastal biodiversity.[2] Those living in poverty in low- and middle-income countries (LMICs) are particularly dependent on natural resources and ecosystem services for their livelihoods, which is why, according to the UN Food and Agriculture Organisation (FAO), "rural poverty has been accepted as both a major cause and result of degraded soils, vegetation, forests, water and natural habitats."[3]

Over the last several decades, humans have changed ecosystems more quickly and extensively than in any comparable period in history, largely to meet rapidly growing demands for food, fresh water, timber and fuel.[4] While these changes have contributed to global economic development, they have also resulted in substantial and largely irreversible degradation of many natural resources and, in some cases, exacerbated poverty among the most vulnerable segments of society. It is now understood that, in addition to undermining most international environmental goals, current trends in biodiversity and ecosystem loss threaten 80 per cent of the UN Sustainable Development Goals (SDGs) related to poverty, hunger, health, water, cities, climate, oceans and land.[5]

The use of digital technology in NRM, such as mobile devices, satellites, the Internet of Things (IoT) and artificial intelligence (AI), is still nascent, but has grown steadily over the last decade. There is increasing evidence that when developed and applied in a customisable and scalable way, digital solutions can significantly improve the efficiency, responsiveness and efficacy of NRM activities. However, current efforts are generally fragmented and poorly documented, making it difficult for stakeholders to learn from best practices, replicate success or identify opportunities for collaboration.

To help address this gap, the GSMA CleanTech programme has conducted new research to explore

1. SFAO, Forests and Poverty Reduction.
2. Convention on Biological Diversity (21 November 2018), People Depend on Marine and Coastal Biodiversity for their Livelihoods.
3. FAO, Poverty, Vulnerability and Livelihood Issues Related to Access to Natural Resources.
4. Millennium Ecosystem Assessment (2005), Ecosystems and human well-being: Synthesis.
5. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (2019), Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

the "digital dividends" of various types of technology on natural resource management in LMICs. Through desk research and stakeholder interviews, we have captured and documented global trends and examples of best practice; identified the common incentives, bottlenecks and benefits NRM stakeholders encounter when deploying digital technology; and highlighted opportunities for the GSMA and its members to enhance the reach, scope and effectiveness of NRM programmes.

Key messages:

Natural resources, livelihoods and poverty are interlinked. The areas of the world that will be most affected by global changes in climate, biodiversity and ecosystem functions are home to many of the world's poorest communities.[6] This, combined with limited access to and rights over natural resources, is a major contributing factor to poverty, particularly in rural areas.[7] A lack of livelihood opportunities can put unsustainable pressure on local ecosystems by eroding community support for protected areas, instigating unsustainable changes in land use, or incentivising participation in illegal logging and poaching activities. Conversely, sound NRM practices can have a positive impact on livelihood creation, reward communities for the ecosystem services they provide and drive sustainable agricultural, fishing and land use practices. Governments, private sector companies and NRM organisations are increasingly aligning climate change objectives with broader development strategies, and our Digital NRM Theory of Change suggests that digital approaches to NRM are likely to contribute to at least 10 of the 17 SDGs.

You can't manage what you don't measure - and analyse. Our review of 131 NRM projects in LMICs shows that digital technologies are transforming the frequency, reliability and transparency of data collection activities, and improving organisational capacity for data visualisation, analytics and evidence-based decision making. Nearly 100 of the NRM projects leverage data collected through satellites, drones or connected devices, and one in five uses artificial intelligence to discover, explore and derive insights from datasets. NRM organisations are highly motivated to work with mobile network operators (MNOs) and other technology organisations to find low-cost connectivity solutions that enable them to transmit data from remote or protected areas. There are also many potential shared benefits from MNOs shifting from IoT projects with a single use case to building IoT platforms that provide a stack of data collection, data storage and data analysis services and applications. This could help drive more sustainable business models, build lower cost IoT ecosystems and create IoT marketplaces that allow multiple parties to access the data being generated across the sector.

6. *Ibid.*
7. FAO, Poverty, Vulnerability and Livelihood Issues Related to Access to Natural Resources.

Digital technologies can incentivise community participation in NRM activities and influence the way people perceive, think about and engage with nature. There is growing recognition that poverty is more than a lack of material necessities and income; it also includes fewer rights and capabilities and less voice and influence over decision making. Although current approaches to NRM often fail to consider the needs and rights of local communities, digital technology—especially mobile—offers new ways to facilitate dialogue between stakeholders, leverage local knowledge and incentivise community participation in NRM activities. Payments for ecosystem services schemes can help support livelihoods by providing financial and other non-monetary incentives to community members who make positive contributions to NRM outcomes. Blockchain and mobile money-based platforms can be deployed to increase the efficiency and transparency of these schemes, and ensure that all participants are fairly rewarded. In places where smartphone penetration is high, mobile apps are being used to "gamify" NRM activities for citizens, such as reforestation efforts or cleaning ocean plastic. This is one example of how participatory approaches can contribute to positive behaviour change, strengthen organisations' fundraising capabilities and provide data that can support environmental research.

MNOs and other technology organisations have a critical role to play. Although NRM organisations are increasingly tech savvy, many still lack the technical skills and expertise required to keep pace with technological innovations, and are typically overly cautious using donor funds to test "experimental" digital solutions. The projects in our dataset indicate that when an NRM initiative receives support from an MNO or other technology organisation, it is twice as likely to leverage emerging technologies like connected devices, blockchain or artificial intelligence. Initiatives from the private sector, such as Microsoft's AI for Earth or Huawei's TECH4ALL programmes, are playing an important role in facilitating shared value partnerships with governments and non-profit organisations, often by providing their partners with access to their company's technical skills, resources and digital expertise.

The GSMA and its members can support ambitious responses to climate challenges. As the environmental crisis becomes even more complex and far-reaching, we expect to see even greater integration between digital technology and NRM activities. We are excited to see that as this sector matures, there will be many opportunities for MNOs and other technology organisations to leverage their resources and technical expertise to make emerging technologies more accessible to, and impactful for, a wide range of NRM stakeholders. In doing so, they will help scale nature-based solutions to climate action, reduce biodiversity loss, optimise nature's contribution to resilient livelihoods and bring long-term value to their organisation. Ambitious and urgent action and a renewed commitment to working in partnership will be critical to achieving the 2030 climate agenda and protecting decades of development progress. The GSMA's CleanTech programme is committed to furthering this cause, and is actively working to help our members and development partners identify opportunities for innovation, facilitate scale and replicate best-practice models to support the transition to more resilient, equitable and decarbonised societies.

Chapter 1:
Introduction

In March 2019, world leaders attending the United Nations High-Level Meeting on Climate and Sustainable Development were told that just over one decade was all that remained to stop irreversible damage from climate change.

The meeting called on leaders to address the global climate emergency with ambition and urgency, underscoring that while no country or community was immune to climate-related devastation, the poor and vulnerable would be the first to suffer and the worst hit.[8] Four months after this meeting, on 29 July 2019, a think tank called the Global Footprint Network estimated that humanity had reached the earliest-ever "Earth Overshoot Day"—the date when the annual demand on nature from individuals, governments and businesses had exceeded what our ecosystems were able to regenerate in that year.[9] This means that we are currently depleting our natural resources at nearly twice the rate they are able to recover.

Today we know with certainty that the effects of climate change, exponential consumption patterns, widening wealth disparities and a growing global population have put increasing and unsustainable pressure on the world's forests, wetlands, rivers, oceans, terrestrial wildlife, marine species and other natural resources. When left unchecked or poorly managed, human activities and other threats can critically undermine the benefits, or ecosystem services, that our natural resources generate, and on which our own survival depends. For instance, forests and "blue carbon" ecosystems, such as mangroves and tidal marshes, help regulate the global climate by absorbing and storing immense amounts of carbon dioxide in their branches, roots and surrounding soils. Protected wetland and savannah habitats support a diversity of plant and animal species that help provide food, maintain soil fertility, deliver clean water to streams and rivers, cycle nutrients, pollinate plants (including crops), and provide a buffer against pests and diseases.[10] Meanwhile, coastal ecosystems can help protect vulnerable communities from the destructive impact of climate change and extreme weather events by dampening the force of storm winds and waves, diminishing flood waters and building up shorelines through the natural distribution of sediment.

Healthy ecosystems are also essential for improving and sustaining human well-being. In many LMICs, natural resources play a critical role in livelihood generation and food security, and can provide a safety net in times of financial hardship.[11] An estimated 150 million people living in poverty count wildlife as a valuable livelihood asset,[12] and 40 per cent of the rural extreme poor—equivalent to 250 million people—live in forest and savannah areas where access to forest products, goods and services is critical to livelihoods and household resilience.[13] Some estimates suggest that upwards of two billion people rely on forest resources for shelter, livelihoods, water, food and energy security.[14]

8. See: UN.org.
9. Global Footprint Network press release on Earth Overshoot Day: https://www.overshootday.org/newsroom/press-release-june-2019-english/.
10. Hoffman, A. Climate change and biodiversity. Australian Academy of Science.
11. OECD (2011), The Economic Significance of Natural Resources.
12. Roe, D. and J. Elliott (14 March 2006). Pro-poor conservation: the elusive win-win for conservation and poverty reduction?
13. See: International Institute for Environment and Development (IIED)
14. WWF (2020), Importance of Forests.

Despite these benefits, human activities are altering ecosystems and reducing biodiversity at a faster pace than in any other comparable time in history. At present, 40 per cent of land on earth is considered degraded,[15] over half of tropical forests worldwide have been destroyed,[16] around one million animal and plant species are threatened with extinction (more than any previous period in human history),[17] and 66 per cent of the world's oceans are significantly affected by human actions, such as plastic pollution.[18]

Pathways to a more sustainable future are still within reach. However, preventing further degradation of natural resources, while also meeting growing demand for their services, will require significant changes in both policies and practices. Digital technologies, such as satellite imagery, artificial intelligence (AI) and Internet of Things (IoT), combined with the expansion of 3G/4G mobile coverage, smartphone penetration and mobile money adoption, all offer new opportunities to support governments, organisations and communities and improve the efficiency, responsiveness and efficacy of natural resource management activities.

Over the last decade, a growing body of evidence has emerged that indicates digital technologies can bring incremental, and sometimes transformational, benefits to NRM stakeholders by altering the way people and processes work, and creating entirely new products and services.[19] Many LMICs are now deploying mobile technology, connected devices and other digital tools as part of their climate change mitigation and adaptation strategies, while seeing positive knock-on effects with broader digital transformation efforts and their capacity to address the SDGs. Recognising these benefits, a growing number of digital initiatives are being funded and delivered with support from donor agencies and intergovernmental programmes, such as the United Kingdom's Department for International Development (DFID),[20] the Food and Agriculture Organization (FAO),[21] the United Nations Environment Programme (UNEP),[22] the World Bank[23] and the United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation (UN-REDD).[24] While our research suggests that most NRM activities are currently driven by governments and mission-led, non-profit organisations, a significant number of projects are now being supported by private sector companies and social enterprises.

Our research found that when developed and applied in a customisable and scalable way, digital solutions can enhance the quality and efficiency of data collection, empower local and global communities to be engaged in conservation efforts and aid real-time decision making. It is also clear from the three case studies presented in this report that digital technology can help scale nature-based solutions to climate action in ways that reduce biodiversity loss and optimise nature's contribution to resilient livelihoods.[25]

In the Philippines, Huawei and Rainforest Connection have deployed acoustic sensors and artificial intelligence to help increase the detection of chainsaws in the rainforest and optimise rangers' patrol routes, and by the end of 2020 they expect that the amount of rainforest protected by the system will be responsible for absorbing 30 million tonnes of CO2 from the atmosphere. Across Sub-Saharan Africa, African Parks and Vulcan Inc. are using EarthRanger (a fit-for-purpose

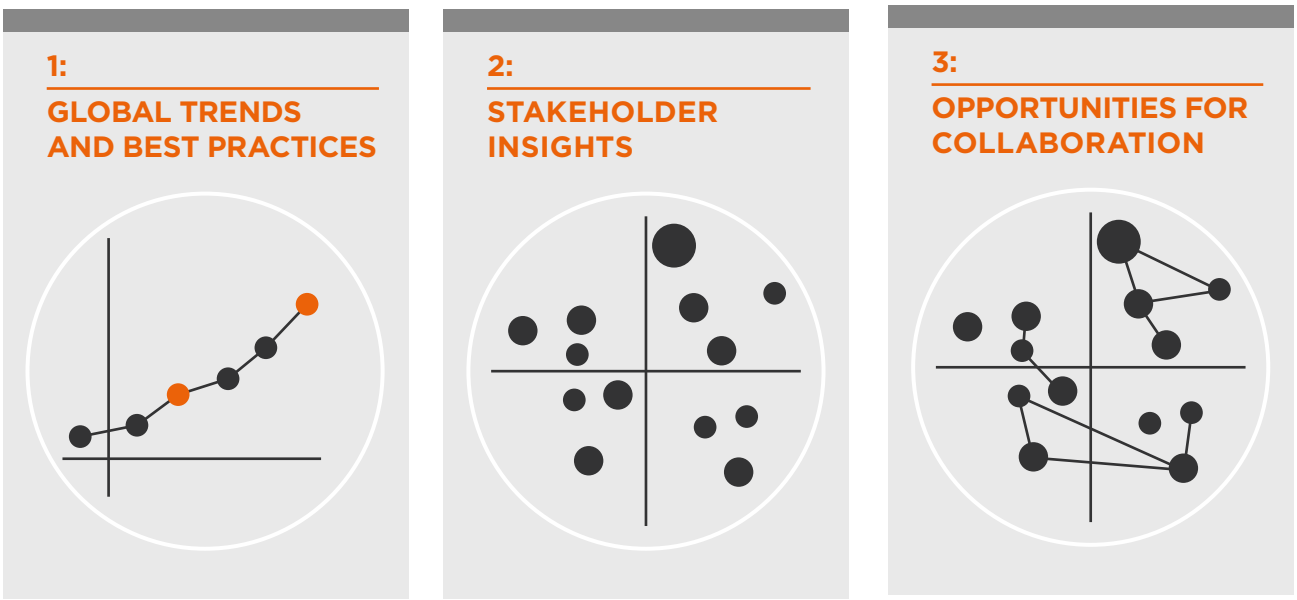
15. UNDP, Biodiversity and ecosystems management.
16. IUCN (November 2017), Issues Brief: Deforestation and Forest Degradation.
17. IPBES (2019), Global Assessment on Biodiversity and Ecosystem Services.
18. *Ibid.*
19. Institute of Development Studies (2016), Ten Frontier Technologies for International Development.
20. DFID (23 September 2019), UK to double efforts to tackle climate change.
21. FAO (8 October 2019), Countering climate change with innovation.
22. UNEP, "Technology".
23. World Bank (12 May 2016), Innovation Centers Help Developing Countries Capture Climate Change Opportunities.
24. The United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation (UN-REDD): https://www.un-redd.org/forest-facts
25. United Nations Global Compact, Nature-Based Solutions to Address Climate Change.

software solution that collects, integrates and displays real-time data from protected areas) to empower park managers and rangers to take immediate, proactive actions to prevent and mitigate threats to wildlife. In Malaysia and the Philippines, Ericsson has worked with local MNOs and a host of other local partners to help local communities restore coastal mangroves using sensors and a web-based dashboard. The project in Malaysia has seen mangrove survival rates soar from 30 to 80 per cent in the project site, while the beneficiary community in the Philippines has reported improved fish catches and the presence of migratory birds not seen for over seven decades.

Research objectives and methodology

Despite the rapid pace of digital transformation in LMICs, the use of digital technology in NRM has been less prevalent than in other areas, such as health, education and agriculture, and is, broadly speaking, a relatively immature field.[26] While there is a growing body of evidence that digital technology can improve NRM outcomes in LMICs, tech-enabled projects remain somewhat fragmented and best practices are not well documented. There is also a particular gap in understanding the role of the private sector, including mobile network operators (MNOs) and other technology organisations, in better supporting NRM organisations and activities.

The objectives of our research were threefold: to capture and document global trends, innovations and examples of best practice in using digital technologies in NRM; to map the specific incentives, bottlenecks, preferences and benefits that NRM stakeholders encounter when engaging with digital systems or services; and to explore synergies between the GSMA, the private sector, digital innovators and development partners to identify opportunities for longer term collaboration.



In support of these objectives, a review of publicly available literature was undertaken to compile an illustrative list of 131 technology-enabled NRM projects that are currently deployed, piloted or in proof-of-concept stage in LMICs. To reveal insights into global trends and innovations, the NRM Heatmap (**Appendix A**) was developed by mapping each of these projects to at least one of 20 NRM activities and to at least one of 16 digital technology types, as outlined in Table 1 (and defined in **Appendix B**).[27] A complete list of the NRM projects identified through the desk research can be found in **Appendix C**.

26. Maffey, G. et al. (2015), Digital technology and human development: a charter for nature conservation.
27. These technology types and NRM activities were selected based on the GSMA CleanTech programme's current areas of interest. Several activities typically considered to be NRM, including water supply and agriculture, were excluded from consideration as they fall under the mandate of other GSMA Mobile for Development programmes.

Table 1

NRM activities and technology types included in this research

NRM category	NRM activities
Terrestrial use types 'Supporting Life on Land'	Forest Management, Securing Land Rights, Wetland Management, Invasive Species and Disease Control, Grasslands, Counter-Poaching, Wildlife Species Preservation, Wildlife Trafficking, Preventing Human-Wildlife Conflict, Wildlife Habitat Protection and Restoration
Marine use types 'Supporting Life Below Water'	Sustainable Fishing Practices, Preventing and Cleaning Ocean Pollution, Marine Counter-Poaching Activities, Marine Species Preservation, Marine Habitat Protection and Restoration
Other Activities	Air Pollution Monitoring and Early Warning Systems, Air Pollution Prevention, Building Climate Resilience, Drought Preparedness, Water Catchment Management

Technology category	Technology types
Software	Call Centres, Interactive Content, Peer-to-Peer Content, Push and Pull Content, Inventory Management Tools, Mobile Payments, Artificial Intelligence, Data Visualisation, Blockchain
Devices	Mobile Devices, Niche Devices, Drones, Satellite, Sensors
Connectivity	Network Infrastructure, Network Software

Based on the results of our desk research, interviews were conducted with stakeholders from the public and private sectors, including donor agencies, NRM organisations (predominantly non-profit organisations) and a broad range of technology organisations, including MNOs, handset and device makers, software companies and equipment providers. A complete list of the organisations engaged through the project can be found in **Appendix D**. Insights collected from the desk research and stakeholder engagement were used to construct a high-level Theory of Change (see **Chapter 3**) and to identify the most promising opportunities for GSMA members, NRM stakeholders and other partners to catalyse digital innovation and enhance the reach, scope and effectiveness of NRM programmes (see **Chapter 4**).

Chapter 2: **Digital trends and case studies**

Figure 1

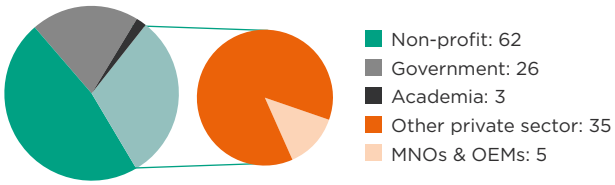
Key Insights from the NRM Heatmap

131 Unique projects identified

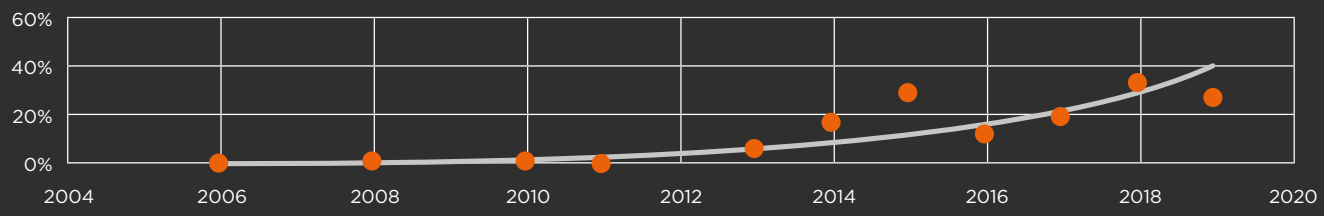
Most common tech pairing: Artificial intelligence and sensors (28 occurrences)

Countries with most projects:
India (21), South Africa (12) and Indonesia (12)

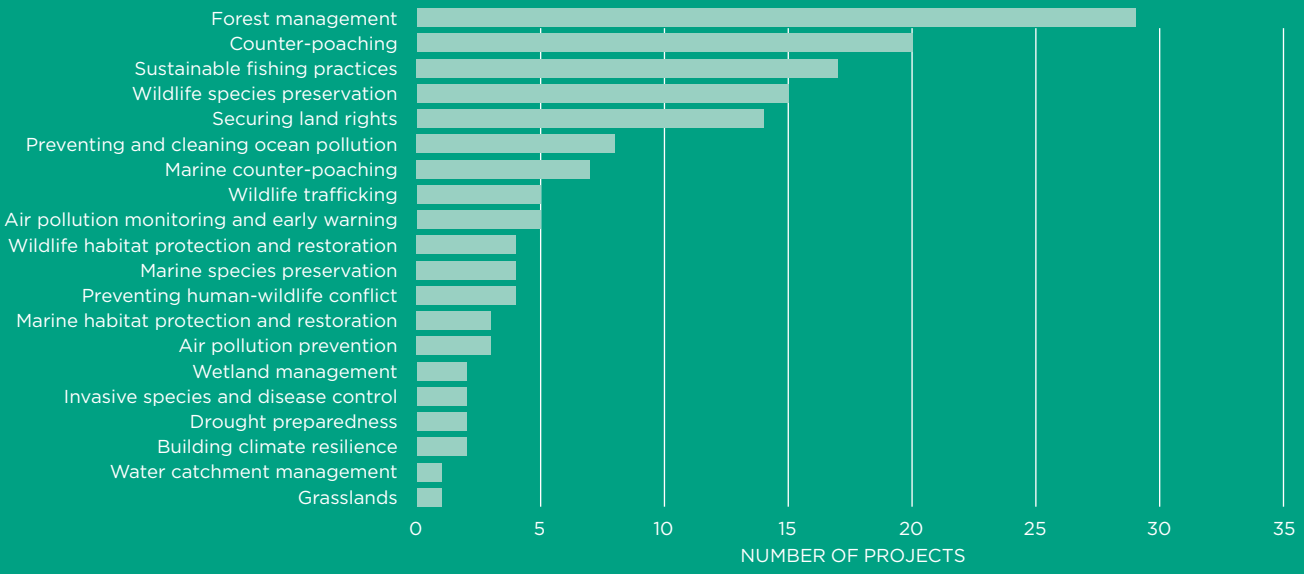
Non-profit NRM organisations are most often the project lead, but the private sector is also well represented



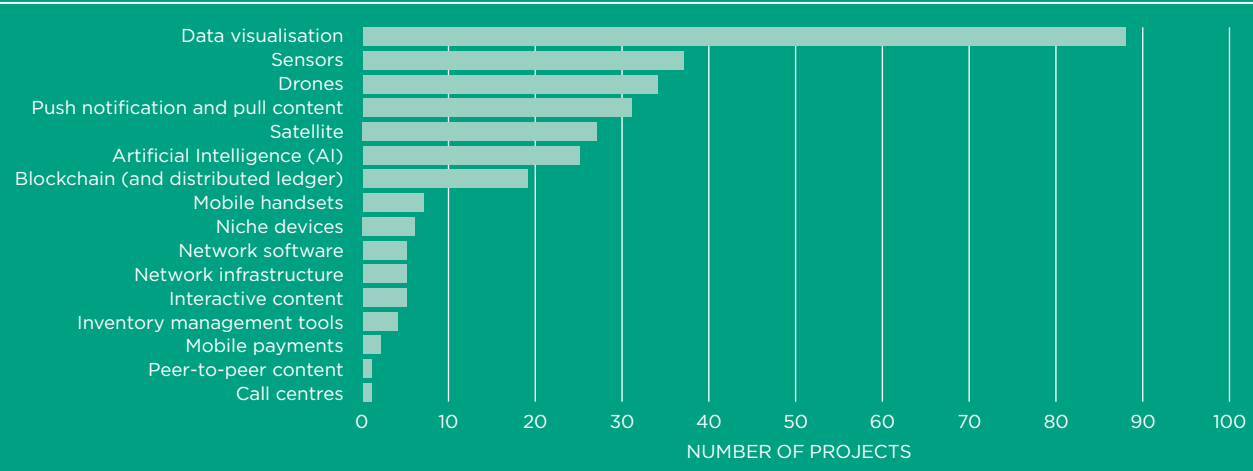
Over half of all projects were implemented in the last three years, and 90 per cent of all projects were implemented in the last six years



'Hotspots' for digital innovation include: forest management, wildlife conservation (counter-poaching and species preservation) and sustainable fishing practices, which account for over half of all projects



A broad range of technologies are being deployed, and 87 per cent of projects use multiple technologies



While there is great diversity in the objectives, structure and scale of these projects, we have found that in almost all cases digital technology is being used in one of the following ways: to enable real-time monitoring and data collection; to support community engagement in NRM activities; and to allow organisations to store, analyse and visualise data (Figure 2).

Figure 2

Three categories of digital technology usage

REAL-TIME MONITORING AND DATA COLLECTION	Connected devices (IoT) and other technologies are used to support data collection and the monitoring of species, people and assets, often in real time or near-real time. **Common technologies used**: Sensors, Satellite, Drones, Camera Traps and Mobile Devices
ENGAGING AND INFORMING COMMUNITIES	A broad range of technologies and approaches are used to influence positive behaviours or to provide communities with the tools they need to actively participate in NRM projects, to access information or support, or to receive payments for ecosystem services. **Common technologies used**: Call Centres, Interactive Content, Peer-to-Peer Content, Push and Pull Content, Mobile Payments and Mobile Devices
DATA MANAGEMENT AND ANALYSIS	AI and other data management tools are used to provide real-time analysis, support decision making, predict trends and promote efficiencies. **Common technologies used**: Inventory Management Tools, Blockchain, AI, Data Visualisation Software

It is evident that **added benefits can be gained by pairing more than one technology in any of these three categories**. This might involve multiple technologies from the same category (e.g. cross-checking satellite information with on-the-ground data collected on mobile apps) or across multiple categories (e.g. using an AI algorithm to analyse data collected from sensors). The vast majority (87 per cent) of projects captured in the NRM Heatmap incorporate at least two types of technology, and the most common pairing—sensors and artificial intelligence—can be found in over 20 per cent of projects. In the Wildlife Conservation sector, for instance, multiple technologies are commonly deployed to provide stakeholders with "situational awareness", a circular process through which data is collected from the field, monitored and visualised in real time, and promptly analysed to aid decision making. In the Philippines, the **B+WISER**[28] project enables on-the-ground patrollers to record observations about changing forest conditions or threats using a smartphone, and data analysis software scrutinises this information to help stakeholders make timely and informed response plans. Similarly, the **Vulcan Skylight**[29] project has developed a monitoring system that combines satellite technology with data analysis software to help law enforcement agencies in Palau and Gabon to identify and capture illegal fishing boats.

The projects captured in the NRM Heatmap suggest that initiatives designed and implemented without support from technology organisations, such as MNOs, are much more likely to leverage established technologies like drones and satellites, rather than emerging technologies such as connected devices, blockchain or AI. This is likely a reflection of resource and skills gaps found in many non-profit organisations or a reluctance to use donor funds to deploy unproven or "experimental" technologies.

Over 60 per cent of the projects led or delivered in partnership with MNOs and other technology organisations deploy emerging technologies, compared to less than 30 per cent of projects that were delivered without private sector engagement.

In addition to their direct environmental outcomes, **many of the projects in the NRM Heatmap are designed to have a positive impact on community livelihoods**. Data collection tools are frequently used to help local communities monitor the health of forested areas, report illegal logging or notify authorities of other misuses of the forest resources on which their livelihoods depend. Animal tracking devices and other types of sensors are deployed to prevent human-wildlife conflicts that might result in the loss of crops, livestock or human life, or to connect local entrepreneurs to income-generating activities in wildlife restoration and tourism. The relatively high number of projects falling under Sustainable Fishing Practices is indicative of a positive trend in using technology to help small-scale fishers, traders, fishing communities and fishing officials access up-to-date information on fish stocks, weather patterns and market prices. Some of these projects train fishers to digitally log their seafood catches on mobile devices or electronic tablets, while others fit boats with satellite transmitters to relay their locations back to land in real time. Once this data is uploaded to a central database, or in some cases a blockchain-enabled decentralised database, it can be analysed to inform management decisions, provide traceability to the fishing supply chain and ultimately lead to more sustainable fishing practices.

It is worth noting that **the use of digital technology can lead to both positive and negative outcomes** for stakeholder groups. For example, monitoring the

28. USAID (2019), Biodiversity and Watersheds Improved for Stronger Economy and Ecosystem Resilience (B+WISER) Program.
29. Bloomberg (2017), Paul Allen Wants to Use Satellites and Software to Fight Illegal Fishing.

location and movement of vulnerable wildlife species in real time can provide a multitude of conservation benefits, but when mishandled this information can help poachers track vulnerable animals or lead to more disturbances from wildlife enthusiasts. Similarly, preventing deforestation can lead to positive outcomes related to carbon sequestration and biodiversity, but local livelihoods that depend on forest products and services might suffer or be displaced through increased monitoring, particularly where land rights are tenuous or poorly enforced. Furthermore, while participatory approaches to NRM can provide communities with new tools for reporting illegal or destructive activities, breaches of non-anonymised data could lead to violence against whistle-blowers. Stakeholders engaged in our research were careful to call attention to the potential unintended consequences of digital approaches to NRM, and stressed the importance of including mitigation strategies in project design and implementation. Engaging with civil society organisations was viewed as an effective way to protect vulnerable communities from negative outcomes, to build trust and cooperation between project stakeholders and to ensure that digital services and platforms are built with community needs and capabilities in mind.

TECHNOLOGIES FOR REAL-TIME MONITORING AND DATA COLLECTION

SUMMARY OF KEY TRENDS

- **Drones** remain popular in marine and forest sectors, and low-cost models are supporting community-based forestry projects. Combined with **mobile** data collection tools, they are highly effective at mapping and documenting land rights.
- **Satellite** images and tools are now highly accessible, due to space agency investments in public-private partnerships and global initiatives, such as Global Forest Watch.
- Interest in **connected devices** is steadily increasing, but the cost of devices remains a key barrier. New business models and collaborations are building IoT ecosystems and generating cost efficiencies.
- NRM organisations are highly motivated to collaborate with MNOs and other technology organisations to find low-cost solutions for providing **network coverage** in hard-to-reach, low-population areas.

The NRM sector is inherently data driven, and over the last decade digital technologies have allowed NRM stakeholders to develop data collection tools and methodologies that provide critical information more frequently, reliably and transparently than ever before. While a multitude of factors have contributed to the wave of innovation seen in the last decade, stakeholders engaged in our research frequently attributed this to the expansion of 3G/4G mobile coverage and increases in smartphone penetration; the availability of off-the-shelf drones that are highly affordable and easy to operate; drastic improvements in the accessibility of satellite data, images and tools; and the proliferation of sensors and other connected devices that are part of the expanding Internet of Things.[30]

31. World Economic Forum (24 May 2018), This is how drones could help to fight climate change.

Drones

The World Economic Forum describes drones as "perfect data collectors" that can help mitigate the impacts of climate change by travelling to places where humans cannot easily go, reducing monitoring costs and improving the accuracy of data collection.[31] They are one of the most frequently used digital technologies in our project list, and there are examples of organisations across all NRM sectors using various combinations of airframes, payloads and analysis capabilities to enable a wide variety of data collection activities. Drones have become a vital tool for small island states and other countries with large marine territories, where they are used to measure sea level rises, fight plastic pollution along coasts, alert authorities of illegal fishing activities and monitor the health of coral reefs. Elsewhere, drones are deployed to monitor protected areas at risk of erosion,[32] patrol forests for signs of deforestation and illegal logging and provide censuses of endangered wildlife and plant species.[33]

Drones have fallen out of favour with some organisations in the wildlife conservation sector, particularly when used for activities that fall outside counter-poaching. This is predominantly due to the high operational costs associated with flying the heavy, sophisticated devices required to monitor huge expanses of protected areas.

In other sectors, however, drones remain popular. In recent years, low-cost drones have become more readily available to resource-constrained NRM organisations and local communities, many of which do not require the devices to log extensive flight times or carry heavy payloads. In Borneo, for instance, low-cost drones fixed with cameras are being used by forest communities to monitor the environmental damage caused by companies that extract the island's natural resources.[34] Photographs taken by the drones are used to identify changes in forest cover and evaluate whether companies are operating outside their designated zones, and evidence of wrongful activity can be sent to government authorities to help them respond appropriately.

When combined with on-the-ground data collection tools, such as mobile devices, drones can also be a highly effective tool for mapping and documenting land rights. Research from the World Resources Institute shows there is a strong and compelling environmental and development case for securing indigenous and community lands as this promotes activities that support conservation and climate mitigation, creates incentives for community members to make productive land-related investments and is an important precursor to government interventions, such as payments for ecosystem services or technical assistance.[35]

DOCUMENTING LAND RIGHTS WITH DRONES: CADASTA'S CUSTOMARY & COMMUNITY LANDS PROJECT

The Cadasta Foundation is a civic and social organisation that develops simple digital tools to collect, analyse and share critical information on land rights. Their platform enables marginalised groups to collect vast amounts of information on their relationship to land and resources, including spatial dimensions, footage from drones, digital maps, video and audio interviews, photographs, paper attestations, tax receipts and other supporting documents. In Odisha, India, Cadasta helped collate data on hundreds of thousands of slum residents to assist them in becoming formally documented land holders. Similarly, the platform helped the Ogiek tribe in Kenya formally document and track their ancestral borders to make legal claims to the land with the government. Through the use of digital technology and partnerships with organisations across 17 countries, Cadasta has helped advance the land and resource rights of approximately 118,000 households and over a million people.

32. SkyEye Pacific: https://skyeyepacific.com
33. Air Shepherd: https://airshepherd.org
34. The Observers (10 July 2016), How drones are helping save forests in Borneo.
35. Veit, P. Land Matters: How Securing Land Rights Can Slow Climate Change and Accelerate the Sustainable Development Goals. World Resources Institute.

Satellites

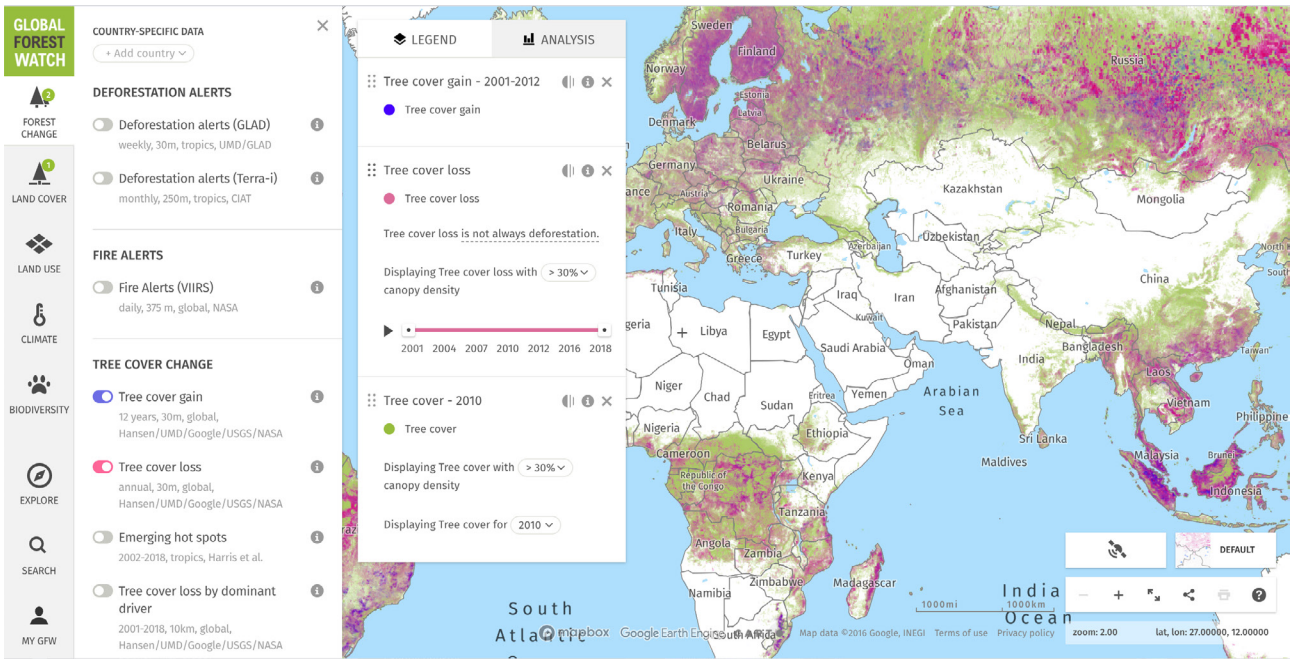
Although not as widespread as drones, over one fifth of the projects in our NRM Heatmap are leveraging data, high-resolution images and monitoring tools provided by satellites. The utility of satellite data lies in its ability to help organisations monitor global patterns at a macro level and in a way that is highly repeatable. For instance, the technology is well positioned to evaluate changes in tree cover or land use over time, to identify emerging hotspots for biodiversity or to provide data on urban expansion.

Once the preserve of specialists and scientists with specific tools and expertise,[36] the accessibility and user friendliness of satellite data has improved dramatically in recent years. National space agencies are increasingly investing time and resources to explore opportunities for satellite data to deliver social good, often by catalysing new public-private partnerships. The UK Space Agency, for instance, has launched a £150 million programme to foster collaborations between businesses, governments and non-profit organisations that provide sustainable, economic and societal benefits to developing economies.[37] GSMA member **Airbus**, through their Defence and Space programme, has a fleet of 27 satellites involved in climate change monitoring that are currently used to measure key atmospheric constituents, land and sea surface topography, and air quality, temperature and humidity.[38] This information helps governments and humanitarian agencies prepare for and manage disasters, generates environmental impact assessments for large industries and allows global leaders to better understand how the earth's climate is changing.

For many organisations engaged in our research, the satellite data and tools provided for free by Global Forest Watch have had a transformational effect on their ability to monitor and raise awareness of deforestation and land change.

Figure 2

Global Forest Watch online dashboard (www.globalforestwatch.org)



36. Catapult Satellite Applications, "Accessing Satellite Data".
37. See: https://spaceforsmartergovernment.uk/ipp/
38. Airbus, "Tomorrow's Weather and Future Climate".

The open platform provides satellite information, imagery and interactive tools (see Figure 3) to governments, private sector companies, civil society organisations and citizens who care about their local forests, to create transparency about what is happening in global forests and to support smarter decisions about how to manage and protect them. **Cool Earth**,[39] a non-profit that works alongside rainforest communities to halt deforestation and its impact on climate change, uses data from Global Forest Watch to monitor canopy cover, to estimate carbon stocks, and to set up an alert system for deforestation events. A new project is also in development to create maps that forecast where deforestation may take place in the future based on past patterns of canopy loss which, if successful, could help to tailor new and more effective conservation strategies.

Sensors and other connected devices

When used in isolation, satellite imagery does not provide a full picture of what is happening on the ground or below the forest canopy in real time. For this reason, organisations like Cool Earth often integrate real-time, on-the-ground data collection tools, such as sensors and other connected devices, which continue to garner interest from a wide range of NRM stakeholders.

In addition to being the most frequently used technology for data collection across the 131 projects captured in the NRM Heatmap, nearly all the organisations engaged through our research reported that they are either evaluating or actively testing how IoT applications can support their programmatic objectives, increase productivity, reduce costs and automate business processes.

Sensors can be used in a range of ways, and the cost, durability and longevity of the devices vary widely. Well-established and higher frequency use cases include deploying sensors to measure air and water temperatures, or attaching tracking devices to vulnerable wildlife species to monitor their location and behaviour. There are also a variety of innovative niche projects and use cases, many of which are still in the incubation or pre-scaling phase. This includes recording devices that transmit sound, photographs and video from protected areas, sensors that measure soil salinity and water levels in coastal areas (see Case Study 3) and even wildlife heart rate monitors that alert authorities to the presence of human intruders or poaching activity.[40]

COLLECTING REAL-TIME DATA ON WILDLIFE: CISCO AND DIMENSION DATA'S CONNECTED CONSERVATION PROJECT

The Connected Conservation project, a joint initiative of Cisco and Dimension Data, uses multiple sensor types and networked devices to reduce poaching activities in African game reserves. The project relies on a combination of connected devices to help authorities detect poachers, including GPS tracking devices, seismic and magnetic sensors, CCTV cameras and biometric scanning. The end-to-end solution can proactively stop people from entering the reserve illegally, and when an incursion takes place the solution triggers an alarm in the park's control centre. An alert with exact coordinates for the incursion is then sent to armed rangers' mobile devices in real time as they patrol both on the ground and in a helicopter. The innovative application of sensors, data analytics and other tech infrastructure has reduced the number of incursions into one reserve by approximately 68 per cent, with poaching in the reserve dropping by 96 per cent in the first year. Following the success of the pilot programme, the project is being expanded into other parks in Africa, including Mozambique, Zambia and Kenya.

39. Cool Earth: https://www.coolearth.org
40. Humane Society International (20 July 2015), New Invention Could Drive Poaching Towards Extinction.

COLLECTING REAL-TIME DATA ON TREE GROWTH: TREEVIA'S FOREST MONITORING SYSTEM

Treevia's forest monitoring system in Brazil, Inventário Floresta, is helping conservationists, researchers and technicians track forest growth rates, estimate whether forests are developing properly and detect early infections or pest infestations in real time. The solution, which has been dubbed "The Internet of Trees", uses wireless sensors placed around trees like a belt. As the tree grows, the device expands, capturing the changes in diameter and transmitting the data to a web-based platform in regular intervals. The data that is collected from the sensors is then combined with satellite images gathered by satellites and analysed by machine learning (AI) algorithms to cross-check how well the forest is growing. While the technology was originally designed to help private sector companies improve the economic and environmental sustainability of their operations, the system is also being used by public authorities to ensure companies are complying with environmental rules and helping to restore and maintain the forests where they operate.

For many organisations **the cost of sensors remains a key barrier to uptake and scale**. While the devices used for high-frequency use cases are becoming widely available, those used for less common NRM activities are typically bespoke and produced in low volumes. This means that many vendors lack experience developing and costing these devices, and the ecosystem has yet to benefit from economies of scale. For this reason, our research uncovered limited evidence of IoT solutions in the sector that have established long-term financial sustainability, and most projects remain funded by philanthropic or donor capital, or through support from the sustainability or corporate social responsibility (CSR) functions of private sector organisations.

However, some promising trends are emerging. Although public and private sector organisations engaged in NRM activities have historically deployed a small number of bespoke devices to generate data for themselves, many are now developing relationships with other like-minded organisations and local vendors to drive demand for home-grown solutions and put downward pressure on the cost of locally produced devices. At the same time, **MNOs are beginning to establish scalable business models by moving away from single use case IoT projects and towards building national or global platforms that can be used for a broader range of use cases**. These platforms would have the potential to provide NRM organisations with a stack of data collection, data storage and data analysis services and applications, create IoT marketplaces that allow multiple parties to access the data being generated across the sector, and help support the growth of IoT ecosystems.

Providing connectivity

It is important to highlight that while 3G or 4G coverage in developing countries is now ubiquitous, the cost of building and operating mobile infrastructure in rural areas can still be economically challenging. It is typically in remote areas with low population density that data transmission from drones, satellites and connected devices can be hampered by sparse or unreliable network coverage. In fact, several stakeholders confirmed that **limited access to reliable 3G/4G GSM coverage remained a significant barrier to adapting or scaling data collection tools**. Some NRM organisations have responded by deploying more expensive satellite communication technology to transmit data, or by creating mobile data collection tools that can function

in low-bandwidth situations. Catalpa's **Lukim Gather App**,[41] for instance, helps local communities in Papua New Guinea report issues and changes to surrounding protected areas. Because the users of the app are in hard-to-reach areas with limited connectivity, the service has been designed to store the data until the user re-enters mobile phone coverage and the information can be transmitted.

NRM organisations engaged in our research were highly motivated to collaborate with MNOs to find connectivity solutions designed for IoT applications that are low cost, use low data rates, require long battery lives and often operate in remote and hard-to-reach locations. In some places, existing cellular networks have already evolved to deliver these services. In areas without GSM coverage, last-mile technologies that use low-power wide-area network (LPWAN) technologies, such as LoRa and Sigfox,[42] present a more immediate, but potentially higher cost and less secure opportunity.[43] In Rwanda's Akagera National Park (see Case Study 2) LoRa networks—a low-bandwidth, low-power networking technology that can cover large areas at relatively low costs—have been deployed to allow camera traps, animal collars and tags, and other sensors attached to fences to send location and spatial data to towers placed at high elevation points around the park. In Zimbabwe, the **Sigfox Foundation**[44] has worked with Lowveld Rhino Trust to test low-cost data collection and transmission technologies that enable conservationists to monitor the location of rhinos. In just four days, the Foundation established a communications infrastructure that covered an entire game reserve and allowed GPS trackers placed in rhino horns to send location data three times a day. The solution appears to be highly scalable—the low-powered sensors only cost $30 per unit—and it is estimated that the devices are capable of sending continuous data transmissions across the Sigfox network for up to three years on a single battery.

MAPPING GSM NETWORK COVERAGE: THE GSMA'S MOBILE COVERAGE MAPS PLATFORM

The GSMA's Mobile Coverage Maps platform was developed in recognition that reliable data on mobile coverage data is the starting point for digital innovation. The platform provides an interactive tool that can be used to identify which areas and populations are covered by 3G and 4G technology, to plan and finance network deployment and to determine where mobile technologies can be leveraged to deliver services, such as natural resource management. The GSMA Connected Society programme developed the maps by collecting data directly from mobile operators and overlaying it with the High-Resolution Settlement Layer, a dataset developed by Facebook Connectivity Lab and the Center for International Earth Science Information Network (CIESIN) at Columbia University. The data estimates human population distribution at a hyperlocal level based on census data and high-resolution satellite imagery, and is enriched by adding socioeconomic indicators and key buildings, such as schools, hospitals and medical centres. The platform currently covers 14 countries in Sub-Saharan Africa.

41. Catalpa International, "Monitoring Protected Areas in Papua New Guinea".
42. Sigfox Technology: https://sigfoxfoundation.org/sigfox-technologyv2/
43. GSMA, Mobile IOT: https://www.gsma.com/iot/mobile-iot/
44. See: https://sigfoxfoundation.org/

TECHNOLOGIES FOR COMMUNITY ENGAGEMENT

SUMMARY OF KEY TRENDS

- **Gamification** can incentivise community participation in NRM and influence positive behaviours aligned with conservation.
- **Participatory approaches** allow NRM organisations to leverage local, indigenous knowledge and provides a cost-effective source of "ground truth".
- **Payments for ecosystem services** can support livelihoods by providing financial and other incentives to community members whose activities deliver positive NRM outcomes. The use of **blockchain** and **mobile money** could increase transparency and ensure that all project participants are rewarded fairly.

Digital technologies can provide organisations with new tools for incentivising community participation in NRM activities, and influencing the way that citizens perceive, think about and engage with nature.[45] As explained by a stakeholder working in marine conservation, while *"it is difficult to build awareness around issues that people aren't engaged, the use of digital platforms for collaboration and awareness assists us in promoting and developing our cause."*

Gamification and awareness raising

Projects captured in the NRM Heatmap show that mobile technology is particularly well placed to raise awareness of environmental issues by gamifying elements of natural resource management, and there is some evidence to suggest this may contribute to positive behaviour change, greater fundraising capabilities and research benefits.[46] The mobile application **Thuru**, for instance, was designed in response to declining forest coverage in Sri Lanka,[47] and encourages citizens to upload photos of trees they have planted and share them with friends. The app functions as a "Facebook for trees" and includes gamification features like points, badges and a leader board to encourage participation and build engagement and awareness about the importance of reforestation. Similarly, the Ocean Conservancy's **Clean Swell** app encourages concerned citizens to collect trash and use the platform to report how much has been gathered.[48] Collection efforts can be shared with family and friends, and "clean-up histories" allow users to see the personal impact they have had on making the ocean a cleaner and healthier ecosystem. The data is automatically uploaded to the Ocean Conservancy's database, delivering a global snapshot of the scale of the problem and providing researchers and policymakers with insights that can inform action.

Participatory approaches

Evidence of digital technologies being used to support information sharing between citizens and NRM organisations (described here as "push and pull content") is also widespread, with at least 31 projects identified in the Heatmap. Many of these participatory approaches are designed around the ethos that communities know best and are a motivated, reliable and cost-effective channel for obtaining ground truth, rather than passive beneficiaries of NRM activities. Participatory approaches to NRM are generally designed to enable citizens to either report or receive critical NRM-related information, and are particularly valuable in contexts where the government lacks the

45. Arts, K. et al. (2015), "Digital technology and the conservation of nature", Ambio (44), The Royal Swedish Academy of Sciences.
46. *Ibid.*
47. Thuru: https://thuru.lk/
48. Ocean Conservancy, "Fighting for Trash Free Seas".

capacity or resources to manage land effectively, or where a lack of information on what is happening on the ground is reinforcing poor NRM practices and governance. Mobile devices are critical tools for these approaches: no other digital technology has the reach, capability and integration in daily life to support the transfer of information between stakeholder groups, and mobile remains the primary means of internet access in low and middle-income countries and payment processes that are essential to their success.[49]

Conversations with NRM stakeholders highlighted that creating a "conservation mindset" in communities is not always straightforward, and sometimes requires project implementers to address other pressing community needs, such as food security, access to healthcare or income generation in tandem with NRM-related objectives. Out of necessity, many NRM organisations are starting to build expertise in community development, but often find this exceptionally challenging and resource intensive given that local communities include people with different needs, challenges and goals. This makes the prospect of partnering with MNOs, which have decades of experience providing communities with relevant agriculture, health, finance, livelihood and other digital tools quite appealing.[50]

For many rural communities, however, preventing the destruction of biodiversity or forest resources will already be top of mind, and the opportunity to take greater ownership of NRM processes, to help bring an end to illegal activities or to be placed on the radar of decision makers and local authorities will be highly motivating. Some stakeholders also suggested that the social component of participatory projects, which bring community members together to discuss how to solve NRM problems, has also been key to success. Stakeholders agreed that engaging directly with individual community members or groups at the start of each project is critical to success, as it can help project implementers understand how digital tools can build on or complement traditional approaches to monitoring natural resources, and ensures that digital services are designed with community needs, capabilities (including digital literacy levels) and preferences in mind.

PARTICIPATORY APPROACHES TO FOREST MANAGEMENT: RAINFOREST FOUNDATION UK'S FORESTLINK

National and local authorities often lack the resources they need to supervise and control a wide range of threats, including illegal logging, illegal mining and oil spills. These activities cause a breakdown in forest habitats, undermining forest and indigenous peoples' livelihoods and destroying ecosystems. The ForestLink platform, developed by Rainforest Foundation UK, enables trained community monitors to use customisable mobile apps to capture evidence of illegal activities or other threats to the forest. Alerts are constructed using a simple survey app, and are sent quickly and easily using SMS texts or a satellite connection to law enforcement authorities, local government and NGOs to help inform their response. The Rainforest Foundation has found that working directly with local communities can help reduce monitoring costs and inefficiencies while also improving forest governance. Real-time alerts from communities in Cameroon are contributing to government legal action against illegal loggers (including fines, suspensions and timber seizures), and alerts in Peru have led to arrests and the seizure of mining equipment across the Madre de Dios region. The project currently operates in communities across Cameroon, the Democratic Republic of Congo, Ghana and Peru.

49. GSMA Connected Society (2019), The State of Mobile Internet Connectivity.
50. See: https://www.gsma.com/mobilefordevelopment/10yearsofm4d/

PARTICIPATORY APPROACHES TO SUSTAINABLE FISHING: XL AXIATA'S MFISH INITIATIVE

The mFish initiative is a public-private partnership that aims to make fishing more sustainable and improve the lives of fishers and their communities in Indonesia. The mobile app was developed by MNO XL Axiata, and provides fishers with information about the weather, tides, wind direction and speed, and their position at sea. Using real-time data from the National Oceanic and Atmospheric Administration (NOAA), the app can also report the location of fish and provide a detailed map of the sea's surface. The app can also be used to collect and analyse catch data, monitor illegal fishing, trace seafood along supply chains and improve fishing safety. To support the mFish pilot, XL Axiata provided kits containing a smartphone, 1GB of free data and a solar charger to fishers, providing them with connectivity while at sea, GPS and maps of their location day and night, and rich messaging capabilities. In 2018, XL Axiata and the Maritime Affairs and Fisheries Ministry released a new app called Laut Nusantara. Building on mFish, the app is overseen by and receives up-to-date information from the Ministry. It also includes educational features, such as information about coral reefs, conservation of marine biota and the threat of pollution.

Payments for ecosystem services

Payments for ecosystem services (PES) schemes are a variety of market-based initiatives that provide payments to community groups or individuals who have agreed to take certain actions that provide environmental value, such as adopting sustainable forest management practices or restoring watersheds. PES is quickly becoming a worldwide practice: there are now over 550 active PES programmes in both developed and developing countries, with $36 to $42 billion in annual transactions.[51] However, these schemes are notoriously difficult to deliver and most projects have failed to achieve scale, either scaling up into a single large programme or scaling out small schemes into multiple projects.[52] There are few examples of tech-enabled PES schemes captured in the NRM Heatmap, which indicates these may still be in a testing phase or are simply poorly documented. Few of the organisations participating in our research have trialled a PES scheme to date, but there was consensus that digital technology could play a crucial role in the monitoring, communicationand payment processes that are essential to their success.

One of the main challenges faced by PES schemes, according to expert interviews, is pinpointing activities or outcomes that can be properly measured and documented, especially in cases where organisations depend on incomplete and unverified data from government ministries or other public stakeholders. In Kenya, for instance, the low quality of government data on forest cover has been described as a key roadblock to forest management PES schemes. In these circumstances, **NRM organisations have recognised that developing their own data collection tools and real-time monitoring capabilities is a prerequisite for implementing PES schemes, and will be a key building block of any project capable of reaching scale.**

51. Salzman, J. (2018), Global market for ecosystem services surges to $36 billion in annual transactions.
52. IIED (2018), Ecosystems, poverty alleviation and conditional transfers: Guidance for practitioners.

Determining which types of incentives are most appropriate for PES schemes can also be difficult. While financial payments are typically considered the most motivating reward, many organisations agreed that financial incentives on their own do not foster commitments to conservation per se, but rather to the specific conservation action(s) for which they are paid. Some PES schemes provide information linked to community livelihoods, such as weather forecasts or guidance on sustainable fishing practices, and in Papua New Guinea where the cost of mobile phone use is relatively high, an organisation called Catalpa has found that **community monitors were highly amenable to receiving mobile phone credit as a reward**.[53] In other cases, communities have benefited most when the PES scheme has helped them develop new digital skills and capabilities, given them ownership over NRM-related data and processes, allowed them to reinforce their rights to land or resources or amplified their voice in decision-making processes.

PES schemes also face challenges ensuring that both financial and non-financial benefits reach all the individuals responsible for the project's success. Local administrative structures sometimes require payments to be made to a cooperative or community organisation, and a lack of transparency on how rewards are allocated to individual members risks only one or two people being fully compensated. At least one of the organisations engaged through our research is actively exploring how blockchain could be leveraged to store and manage data collected through PES schemes, to document financial and non-financial value that communities receive as compensation for their services and to facilitate digital payments. A relatively high percentage of the PES schemes captured in the NRM Heatmap are already using blockchain-based payment platforms. In some projects, blockchain-enabled payments are distributed to community bank accounts, while in others participants receive payments on their mobile phone in a digital currency. However, NRM organisations participating in our research often indicated an interest in pursuing mobile money-based PES payments.

Mobile money services, including those linked to blockchain payment platforms, could provide a more convenient, cost-effective and transparent way for organisations to transfer entitlements to beneficiaries. The high uptake of mobile money services in low and middle-income countries, particularly among segments of society targeted by PES schemes, suggests that opportunities for collaboration with MNOs would be valuable.

53. Based on stakeholder interviews. For more information, see: https://catalpa.io/projects/lukim-gather/.

PAYMENT FOR ECOSYSTEM SERVICES: RAINFOREST FOUNDATION US

Rainforest Foundation US is partnering with local community organisation and tech partner Regen Network in Peru to use blockchain technology to track, verify and reward communities for protecting and regenerating forests. The project is being piloted in the Ticuna community in the north of the country, where local community members have agreed to collectively conserve 1,000 hectares of Amazon forest and simultaneously undertake an ambitious reforestation project on land that is currently degraded. The community has committed to zero deforestation, and will actively patrol their territory using their existing community monitoring programme. The community will also use drones and other tools to investigate deforestation alerts they receive from the Global Forest Watch system. The community will be compensated for maintaining net zero deforestation through Regen Network's blockchain-based payment system, which deposits funds into a communal bank account. Families in the community have agreed to use the collective funds to help plant, tend and monitor the forest over the coming years. Compliance with tree planting will be measured and verified by satellite data, as well as by community forest monitors who provide quarterly updates on the trees planted and their growth.

TECHNOLOGIES FOR DATA VISUALISATION AND ANALYSIS

SUMMARY OF KEY TRENDS

- **Data storage and visualisation** technologies provide numerous, dynamic ways for NRM organisations and citizens to discover, explore and derive insights from data. There are numerous examples of blockchain databases being used to create permanent public records related to land rights.
- **Artificial intelligence and big data** provide powerful tools for data analysis and automated decision making, but the cost and technical expertise required to develop analytical tools are prohibitive for non-profits. Technology organisations could fill this gap by deploying their skills and AI products, or by creating open source AI algorithms.

Although organisations have welcomed digital technologies that increase the scale and granularity of their data collection activities, processing and deriving insights from vast amounts of data can quickly become a burdensome and time-consuming task. This is particularly true for organisations that lack the funding or technical expertise necessary to deploy data visualisation and analysis tools.

Data visualisation technologies

Data visualisation technologies are the most commonly deployed technology in the NRM Heatmap, and often provide low-cost, dynamic ways for NRM organisations and everyday citizens to discover, explore and derive insights from data. Interactive platforms, such as **BreezoMeter**[54] and **Digital Earth Africa**[55] are helping organisations leapfrog data collection processes by converting

54. BreezoMeter Air Quality App: https://breezometer.com/air-quality-map
55. Digital Earth Africa: https://www.digitalearthafrica.org/

raw datasets into "analysis-ready" platforms that are easy to navigate and use in decision making. Geographic information systems (GIS) are more sophisticated data visualisation tools that can be used to gather, integrate, manage and analyse data. These systems typically layer datasets onto a map so that users can identify unexpected patterns, relationships and situations, and ultimately make smarter decisions. In Burkina Faso, the World Bank (in conjunction with the government) is supporting a large-scale, community-led tree planting effort that aims to infuse new life into their land. Mobile data collection tools are used by young people to monitor programme activities in real time, while a GIS system designed by **ESRI**[56] is used to monitor changes in forest cover, help analyse which planting strategies are generating the highest growth rates and measure the ecosystem services provided by new trees.

DATA VISUALISATION TO SUPPORT SUSTAINABLE FISHING: GOOGLE, OCEANA AND SKYTRUTH'S GLOBAL FISHING WATCH

Global Fishing Watch promotes ocean sustainability through greater transparency, and uses satellite technology, cloud computing and machine learning to visualise, track and share data about global fishing activity in near real time for free. First, data is collected from automatic identification systems (AIS), a GPS-like device that ships use to broadcast their position to avoid collisions. Machine learning algorithms are then used to look for patterns and learn how to determine the type of each ship, its size, what kind of fishing gear it is using and where and when it is fishing based on its movement patterns. This information is then made publicly available through an interactive online map and downloadable data. Users can create heat maps to see patterns of commercial fishing activity, view the tracks of individual vessels and overlay information like the locations of marine protected areas or different countries' exclusive economic zones. The platform is helping to enable scientific research, advocate for better policies to support marine protection, tackle overfishing and improve the way fishing is managed.

Artificial intelligence

Artificial intelligence (AI) gives organisations the ability to analyse and derive insights from immense datasets using predetermined algorithms that can detect infrequent or complex patterns in near real time. The NRM Heatmap and stakeholder interviews have shown there are fewer examples of AI projects being deployed in NRM compared to other sectors, and these projects have had relatively small impact to date. AI algorithms must be highly bespoke, designed for a narrowly focused problem and fed with vast amounts of very specific data. This makes developing AI algorithms, whether analytic or predictive, a time-consuming and expensive process and a challenge to scale and replicate AI projects across NRM activities, even across projects with the same type of activity. At present, the resources and technical expertise required to develop and apply AI algorithms represent a significant barrier for many NRM organisations.[57]

While there are some opportunities for NRM organisations to access AI technologies through online marketplaces, training platforms and open source machine learning libraries, many are seeking opportunities to fast-track the deployment of these technologies by partnering with academic institutions or technology organisations.

56. Esri: https://www.esri.com/en-us/home
58. Stakeholder interviews, technology and NGO sector.

Conversations with MNOs and other technology organisations indicate there is a relatively high degree of interest in helping NRM organisations develop new AI applications.

Furthermore, there appears to be broad consensus from multiple stakeholder groups that the ability of technology organisations to provide access to technical skills, resources and digital expertise to fill this skills gap can be more valuable than project funding. Microsoft's **AI for Earth programme**,[58] for instance, helps put Microsoft Cloud and AI tools into the hands of organisations addressing a wide range of environmental challenges. The initiative deploys teams of people who can help simplify and "change the plumbing" in these tools so that NRM organisations can focus less attention on technology development and more on delivering environmental value. Similarly, Huawei's **TECH4ALL programme**[59] (see Case Study 1) leverages the organisation's cloud services and AI data centres to help NGOs innovate and work better in the digital ecosystem. While these types of NRM projects are still difficult to implement if organisations need immediate commercial returns, private sector stakeholders agreed that the development of new AI applications—even when incubated by sustainability or CSR functions—may eventually provide long-term commercial value, and could also drive the development of "bridging technologies" that will help them realise the full promise of IoT solutions.

The development and dissemination of open source AI platforms could provide a role for MNOs and technology organisations in driving broader adoption of AI in NRM.

These would offer core algorithms and generic design architectures for various NRM use cases, allowing organisations with limited capacity or expertise to leapfrog many of the design steps and overcome some of the challenges associated with AI adoption curves. Expert interviews suggest that open source codes could be an ideal way to help NRM organisations get "90 per cent of the way" to the specific algorithms needed to deliver their project, while also letting developers see how data is being used by the NRM community. **ATLAN Space** has applied such a modular approach to their AI development, using frameworks that can support multiple use case applications.[60] Each of their AI models operates on three axes or modules; two use base source codes that are relatively broad and can be applied to numerous use cases, while the other is tailored to a specific use case. For its initiative on illegal fishing surveillance, for instance, two of the modules work together to help drones identify activity hotpots, define the optimal flightpath and react to changing conditions. These can be readily applied to many other drone use cases, while a third module providing "cognitive vision" is highly customised and requires very specific datasets.

58. Microsoft AI for Earth: https://www.microsoft.com/en-us/ai/ai-for-earth
59. Huawei TECH4ALL: https://www.huawei.com/minisite/TECH4ALL/en/
60. Stakeholder interviews with ATLAN, March 2020, and ATLAN Space website: http://www.atlanspace.com/

ARTIFICIAL INTELLIGENCE AND BIG DATA: USC AND MICROSOFT'S PAWS PROJECT

To effectively patrol expansive wildlife areas with limited resources, park rangers need to know where poachers are likely to strike. In Uganda, the Protection Assistant for Wildlife Security (PAWS) uses AI to aid conservationists in the fight against poaching with machine learning, AI planning and behaviour modelling. Developed by researchers at the University of Southern California (USC) and supported by Microsoft's AI for Earth initiative, PAWS analyses historical poaching data, patrol effect records and geospatial park data with machine learning algorithms. The system generates heat maps that show likely attack areas and the effort required to reach them, helping rangers plan better patrol routes. These routes are also randomised to keep poachers from learning patrol patterns, and undermining any corrupt rangers who let poachers know in advance where counter-poaching efforts may take place. Considering the Uganda Wildlife Authority uses 50 to 90 per cent of its budget on ranger patrols, the added efficiencies could allow more of this budget to go towards programmes like tourism development, invasive plant removal and undercover operations to stop wildlife trafficking.

ARTIFICIAL INTELLIGENCE AND BIG DATA: TELEFÓNICA BRAZIL'S BIG DATA FOR AIR POLLUTION

Telefónica Brazil (Vivo) is working with the municipalities of São Paulo to harness mobile network data to combat the adverse health effects of air pollution. Algorithms developed by Telefónica use machine learning and anonymised data from the mobile network, combined with data from weather, traffic and pollution sensors, to monitor and predict pollution levels over the entire city. The mobile data can include active events, such as a voice call or SMS, and passive events, such as devices synchronising with cell towers. The data is shared with the municipalities of São Paulo and integrated in their traffic and pollution management processes. The approach can yield insights more cost effectively than direct observation of pollution levels, and on a regular, more dynamic basis than is possible with more traditional data collection methods. The solution can also predict pollution levels 24 to 48 hours in advance, enabling local authorities to take preventive steps if emissions could endanger human health.

Case study 1: **Guarding rainforests**

FOREST MANAGEMENT IN CONTEXT

Forest management has historically lagged behind most other sectors in the adoption of digital technology, in part because the majority of forests in LMICs are both publicly owned and conservatively managed, and the remaining forests are typically found on private plots of land smaller than one hectare.[61] However, the cluster of projects in the NRM Heatmap is indicative of a positive shift over the last decade.

It is widely recognised that halting and reversing deforestation would deliver a cost-effective and nature-based solution to curbing climate change. According to one estimate, the world's existing tropical tree cover alone could provide 23 per cent of the climate mitigation needed over the next decade to meet goals set in the Paris Agreement in 2015.[62] For this reason, global mechanisms such as REDD+[63] are building the capacity of governments and organisations in developing countries to recognise the value of the goods and services provided by healthy forests, and offering incentives for improved forest conservation efforts. At the same time, bold new initiatives are leveraging digital technologies, such as satellites, sensors, camera traps and mobile apps to provide local communities, government ministries, conservationists and other stakeholders with a better understanding of what is happening in protected areas.

There are relatively few limitations to the types of technology that can be deployed in forests, and this is reflected in the Heatmap—no other NRM activity uses a wider array of technologies. Forest management has benefited particularly in recent years from the utility and availability of low-cost drones that can be used to monitor forest cover and changes in land use, even at a small scale (there are examples of community-owned and operated drones for forest monitoring). There have also been dramatic improvements in the accessibility of satellite data, imagery and tools that can empower individuals and organisations of all sizes to better protect forests. These are typically provided by national space agencies, which are increasingly investing time and resources into tackling climate change through public-private partnerships[64] or through global initiatives, such as Global Forest Watch.[65]

61. McKinsey & Company (June 2018), Precision forestry: A revolution in the woods.
62. National Geographic, "Deforestation explained".
63. Reducing emissions from deforestation and forest degradation (REDD+) is a mechanism developed by Parties to the United Nations Framework Convention on Climate Change (UNFCCC). See: https://www.unredd.net/about/what-is-redd-plus.html
64. The UK Space Agency, for instance, has launched a £150 million programme to provide a sustainable, economic or societal benefit to undeveloped nations. See: https://spaceforsmartergovernment.uk/ipp/.
65. See: http://www.globalforestwatch.org

Guarding rainforests: Huawei and Rainforest Connection

Tropical rainforests cover approximately eight per cent of Earth's land area, yet they are home to over half our planet's terrestrial animal species and play a critical role in cleaning the air, managing water supplies and regulating ocean currents, wind patterns and rainfall.[66] Rainforests also stabilise local and global climates by absorbing and storing massive amounts of carbon dioxide: UN-REDD estimates that forests and forest soils store more than one trillion tonnes of carbon, more than all the carbon currently found in the atmosphere.

However, tropical forests are being destroyed at a rate of at least 31,000 square miles every year, releasing much of the carbon they store into the atmosphere as carbon dioxide and other greenhouse gases. It is estimated that tropical forest loss accounts for nearly 10 per cent of the world's annual carbon dioxide emissions, making tropical deforestation a higher carbon emitter than the European Union.[67] Virtually all deforestation in tropical and non-tropical forests is driven by human activity: approximately 48 per cent is attributed to subsistence farming, while industrial agriculture and logging are responsible for 32 per cent and 14 percent, respectively.[68]

In 2014, the non-profit Rainforest Connection (RFCx)[69] was founded with the aim of giving citizens and conservation partners new ways of understanding the rainforest through "bioacoustic monitoring", a process through which audio recording devices and data transmission systems are deployed in forests to monitor the sound of animals and human activities in real time. As remote sensing technology advances and becomes less costly, proponents argue that bioacoustic monitoring could become a critical tool for ecological study and forest conservation.[70] Boosted by collaboration with the private sector, including Huawei's TECH4ALL programme,[71] RFCx's monitoring system has now been scaled across five continents.

In the Philippines, Huawei and RFCx are working together to test a new monitoring system that leverages connected mobile devices and AI to prevent illegal logging and animal poaching in five protected areas in Palawan, an area described as the country's last ecological frontier.[72] Delivered in partnership with the government's Department of Environment and Natural Resources (DENR), PLDT wireless and mobile operator Smart Communications, the Rainforest Guardians project helps detect the sound of human activity (e.g. chainsaws or motor vehicles) and captures data on animal patterns and behaviours.

It is estimated that illegal logging accounts for between 50 and 90 per cent of the timber trade in tropical countries,[73] yet detecting chainsaws and other sounds related to human activity can be challenging.

66. Rainforest Alliance: https://www.rainforest-alliance.org/issues/forests
67. Fritts, R. (18 October 2018), "Tropical deforestation now emits more CO2 than the EU". Mongabay.
68. UN-REDD, "Forest Facts".
69. See: https://rfcx.org
70. Welz, A. (5 November 2019), Listening to Nature: The Emerging Field of Bioacoustics. YaleEnvironment 360
71. See: https://www.huawei.com/minisite/TECH4ALL
72. MyCebu.ph (19 March 2020), "DENR, Smart, Huawei join hands to save Philippine rainforests". Press Release.
73. NEPCon, "Illegal logging".

This is due to the cacophony of nature, and the fact that it is extremely difficult for the human ear to differentiate the sound of chainsaws from other sounds in the forest.

To address this challenge, the Rainforest Guardians project connects upcycled Huawei smartphones to solar panels and microphones (see photos below), allowing the RFCx system to livestream the sound of the forest 24 hours a day. The mobile devices have proven to be extremely durable—RFCx estimates that they can operate non-stop for two years without human intervention—and are less expensive and easier to power than most other types of connected devices. The recorded audio is then uploaded in real time to the cloud through wireless networks. The project in the Philippines is the first instance where RFCx has worked with an MNO to support the monitoring system, with Smart providing wireless connectivity to all the designated pilot sites.

Top: *RFCx CEO and founder Topher White prepares to install the sensors;*

Bottom, left to right: *the mobile recording devices are placed inside a protective box and powered by strips of solar panels. (Photos courtesy of RFCx and Huawei)*

Once uploaded to the cloud, Huawei's deep learning AI models analyse the data and instantly detect the sound of vulnerable animals (such as spider monkeys [74]), or illegal human activity. Huawei worked with wildlife experts to label initial recordings from the rainforest in a cloud archive, and AI specialists used this baseline data to help improve the AI model so that it could function autonomously with a high level of accuracy. The audio recordings are accessible to DENR forest rangers, who also receive real-time alerts when the monitoring system detects the sound of chainsaws, trucks and other indicators of forest destruction so that they can respond appropriately. The DENR has welcomed this collaboration, noting that it has already had a positive impact on the country's forest cover, supported law enforcement and complemented existing monitoring systems.[75]

The AI model deployed in the Philippines has been used in 10 other countries and has raised the detection rate of chainsaws to 96 per cent. Rangers have also indicated that they are now traversing less ground to find illegal loggers and poachers, and experiencing fewer false alarms. In Brazil, the model has been used to support indigenous tribes in the Tembe territory who in 2015 estimated that up to 80 per cent of their land was occupied by illegal loggers, illegal settlers and drug cartels.

The Guardian system is now alerting the tribe in real time when anyone encroaches on their land, allowing rangers to block feeder roads, seize trucks and equipment and detain illegal loggers.

Huawei's TECH4ALL programme believes that the Rainforest Guardian solution can be quickly and easily adapted to more countries and more conservation scenarios, and expects that in 2020 the system will triple the amount of rainforest it covers, from 2,000 to 6,000 square kilometres. At this scale, RFCx estimates that the amount of rainforest protected by the system will increase the absorption of CO2 by 30 million tonnes, which is the equivalent of taking six million cars off the road. RFCx and Huawei will also continue to optimise the bioacoustics platform in 2020 by improving web and mobile interfaces, and by developing an API that aggregates acoustic data from various sources. This will enable AI learning models to ingest and analyse audio at a much greater scale, allowing it to better monitor ecosystem health and protect other endangered habitats and animal species.

For more information, see: rfcx.org or huawei.com/tech4all

74. See: https://www.huawei.com/en/about-huawei/cases/rainforest2
75. MyCebu.ph (19 March 2020), "DENR, Smart, Huawei join hands to save Philippine rainforests". Press Release.

Case study 2: **Protecting wildlife**

WILDLIFE MANAGEMENT IN CONTEXT

The people and organisations responsible for protecting the earth's most iconic and endangered wildlife species face a multitude of complex and interrelated challenges. According to the National Wildlife Federation, altered climate conditions have already been linked to changes in wildlife distribution, reproduction and behaviour, and warming temperatures will cause these fluctuations to continue.[76] Climate change and human activities are also causing healthy, natural landscapes to shrink and become more fragmented, leaving wildlife with less than half the space they once had to roam and pushing them into situations where conflict with humans is inevitable. Even where physical barriers separate wildlife from neighbouring communities, limited livelihood opportunities can aggravate human-wildlife conflict by driving demand for bushmeat, or by creating incentives to participate in the increasingly militarised poaching networks that drive the $20 billion a year illegal wildlife market.[77] Furthermore, conservationists and protected area managers are often charged with monitoring vast expanses of land with limited resources and without access to streamlined, easy-to-use data that provides a full picture of what is happening on the ground in real time.[78]

Over the last decade, digital technology has played an increasingly vital role in helping conservation organisations respond to the impacts of climate change on both wildlife and people, a trend at least partly influenced by the rhino crisis that struck the African continent in 2010. According to expert interviews, to avoid local extinctions, conservation organisations were compelled to explore new ways to modernise their counter-poaching efforts, creating a surge in (often philanthropic) funding and a new openness to investing in digital technology. Over the years, conservationists have been able to leverage or repurpose the digital tools developed and deployed for law enforcement—tracking collars, mobile data collection tools and sensors that detect gunshots or fence breaches, just to name a few—to improve how they monitor and understand animal behaviours, protect against invasive species, restore the health of wildlife habitats, prevent human-wildlife conflict and improve livelihoods in local communities (for instance, by preventing crop raids, providing agricultural advice and support or sharing the benefits of tourism). The Heatmap also reflects that while drones have proven useful in counter-poaching situations (for instance, by locating poachers and hovering over them until rangers arrive), they are not usually the most cost-effective technology for broader conservation work.

76. Conservation in a Changing Climate, "Manage Wildlife for Climate Change Resilience."
77. African Parks: https://www.africanparks.org/sites/default/files/uploads/resources/2018-11/20181029_African Parks Booklet_Update_V18_General Booklet_Web_English_Single Pages.pdf
78. EarthRanger: https://earthranger.com/About-Us.aspx

Protecting wildlife: African Parks and Vulcan Technologies

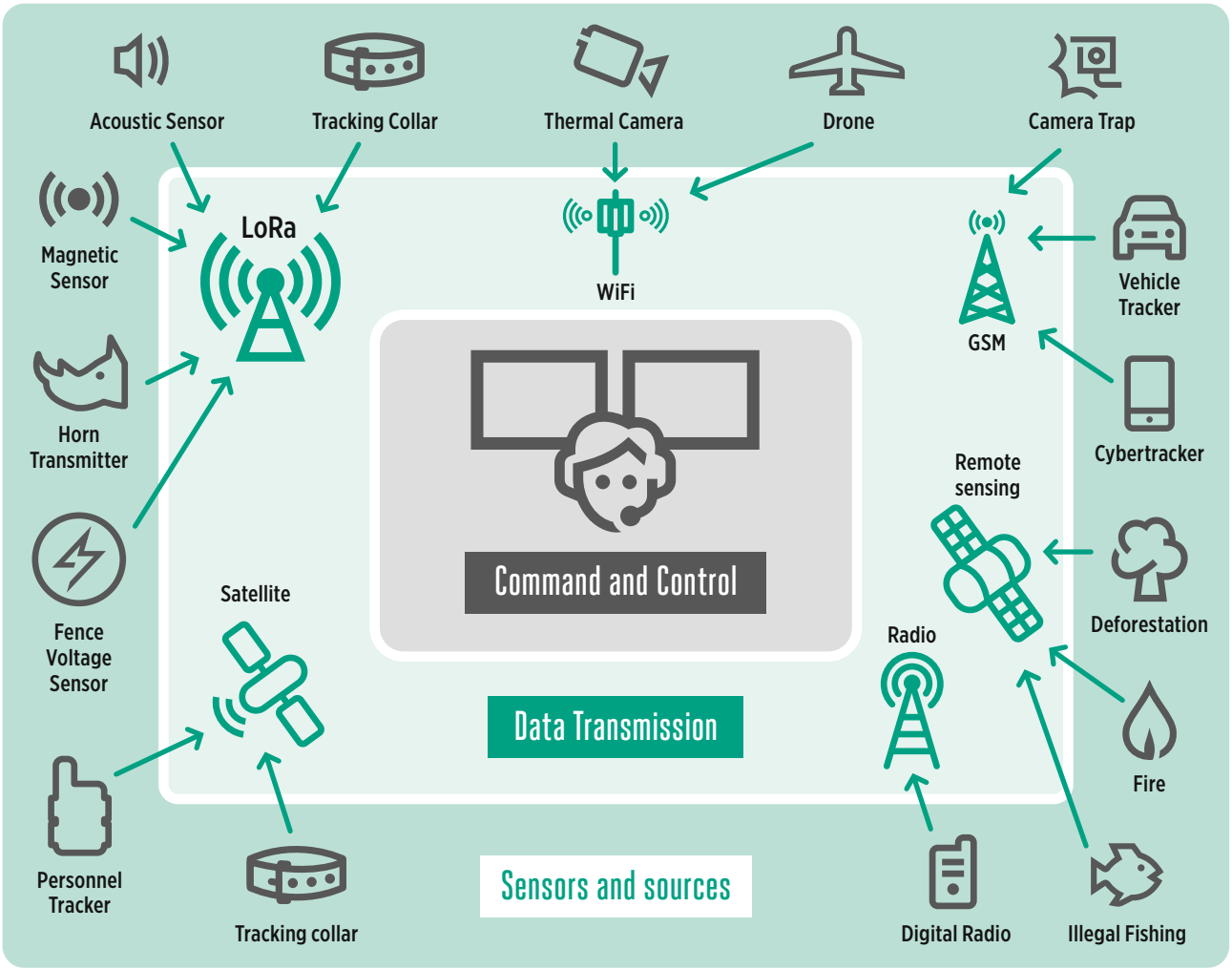
Garamba National Park, located in the northeast corner of Democratic Republic of Congo, has been "threatened and battered from all sides[79]" for over two decades due to localised warfare and militarised poaching. The park's location, densely forested areas and abundance of ivory have made it "a crossroads, an enticement and sometimes a battleground" for rebel armies and other dangerous intruders.[80] Once home to approximately 22,000 elephants, by the early 2000s, armed and rebel groups using the ivory trade to fund their criminal activities reduced the population to fewer than 1,200, while also driving the northern white rhino into local extinction.

To halt the park's destruction and bring stability to the area, in 2005 the government entered into partnership with a non-profit conservation group, African Parks, which began deploying a broad range of digital technologies to support counter-poaching activities and help rangers "see things that were otherwise hidden".[81] Elephants were fitted with tracking collars so they could relay information in real time to African Parks' GIS, allowing staff to observe the animals' position, movements and even their speed in real time as icons on a digital map. Aerial photography analysis pointed to expanding trail systems, wildfire patterns suggested new places poachers might approach or avoid and probable river-crossing points were identified. Data analysis tools also helped staff predict the movement of elephant herds and direct resources and rangers to places they were likely to intercept poachers. Combined with community development efforts, the new strategy has significantly reduced illegal activity in the park, elephant poaching has dropped by 90 per cent, no rangers have been killed in action by armed poachers since 2017 and key wildlife populations have either stabilised or are increasing.[82] The growing and increasingly professionalised ranger force also provides security to tens of thousands of people living in the communities surrounding the park, slowly returning peace to the area.

With 17 national parks and protected areas under its mandate covering 13.5 million hectares, African Parks has the most land under protection of any NGO in Africa, and they manage the continent's largest counter-poaching force. The organisation's mission is to ensure that every park is ecologically, socially and financially sustainable for the long term through effective wildlife conservation, by assuming control of all law enforcement (counter-poaching) activities and by supporting economic development and poverty alleviation in surrounding communities. Governments, multi-lateral institutions, conservation organisations, family foundations and individuals provide funding to the organisation, and to building sustainability they create revenue through tourism and associated enterprises compatible with conservation, reducing donor dependence over time as far as possible.

79. Quammen, D. (12 November 2019), To save wildlife, African governments turn to private management. National Geographic.
80. *Ibid.*
81. Esri (11 February 2020), African Parks Uses New Technologies to Combat Poaching and Protect Animals.
82. African Parks: https://www.africanparks.org/the-parks/garamba

African Parks has invested extensively in the deployment of contextually appropriate technologies, information networks and communications to provide decision makers with a high degree of situational awareness: a circular process through which data is collected, monitored and visualised in real time, and quickly analysed to create an informed response plan. Key wildlife species, park assets and individuals are tracked in near real time using a combination of connected devices. This includes mobile-enabled data collection tools (for instance, text messaging services and the Cybertracker App[83]); remote feeds from fence alerts, camera traps or acoustic sensors; and tracking devices, such as animal collars, ear tags and digital radios.



Due to their unique operating model, African Parks often works in remote or hard-to-access places where GSM network coverage is not consistently available, and where it can be both challenging and expensive to ensure that devices, sensors and people maintain connectivity. In 10 of their parks, digital radio technology has been installed to allow for two-way voice communication and real-time

83. See: https://www.cybertracker.org

tracking of ranger teams. In Rwanda's Akagera National Park, LoRa networks—a low-bandwidth, low-power networking technology that can cover large areas at relatively low costs—allows location and spatial data from camera traps, animal collars and tags, and sensors attached to fences to send constant signals to towers placed at high elevation points around the park. The LoRa network can be scaled to incorporate up to 100,000 connected devices and allows African Parks to put a sensor on virtually anything, from an animal or an anti-poaching K9 unit to one of the park's entry gates.[84]

In areas with consistent 3G or 4G network coverage, African Parks is able to facilitate mobile communication with local communities, which helps to further involve them in the management of a park—part of a process the organisation calls "building a constituency for conservation".[85] In places like Garamba, or Zakouma National Park in Chad, community members can support law enforcement efforts by sending text alerts to park staff when unfamiliar people, who might be poachers or scouts for rebel militias, are seen in the area. In the future, African Parks hopes to enable communities to submit conservation data directly to park staff. Cooperative groups or local guides could help report the movements of animal species to reduce conflict with neighbouring communities, or they could protect local ecosystems by documenting the location of invasive plant species. African Parks also works to position conservation as a valuable use of land by delivering other tangible benefits to local communities. In addition to providing greater access to health care and education, they seek to establish conservation-led economies that create jobs, stimulate local micro-enterprise development, promote local procurement, develop skills and knowledge and ultimately improve livelihoods.[86]

To ensure that park rangers and staff can observe and respond to real-time data collected from the field, African Parks has installed an innovative domain awareness system called EarthRanger in six of their parks. EarthRanger was developed by Vulcan Inc.,[87] a private sector organisation that pursues a wide range of initiatives and projects to address some of the world's most difficult challenges facing oceans, climate, conservation and communities. Part of Vulcan's conservation work is focused on developing innovative technologies that help protect endangered species and address the threat of wildlife trafficking.[88]

Launched in August 2015, EarthRanger is a fit-for-purpose and easy-to-use online software solution that collects, integrates and displays all historical and real-time data available from a protected area, empowering park managers and rangers to take immediate, proactive actions to prevent and mitigate threats. The system provides users with a unified view of all the animals, sensors and incidents in their protected area and offers key insights into meaningful trends, including animal movements and behaviours, ecological changes (such as the spread of invasive species) and law enforcement incidents. Accessing EarthRanger only requires a web browser and internet connectivity, and the system's highly configurable security model enables wildlife parks to maintain complete control over who is able to view sensitive data, such as the location of rhinos and other highly vulnerable species. As a non-profit organisation, Vulcan does not sell or profit from EarthRanger, nor do they seek to recover the cost of the system's development. Rather, they provide the system and ongoing support free of charge to an organisation as long as the software is being used to promote conservation.

84. Toor, A. (20 July 2017), This African park has a high-tech plan to combat poachers.
85. For more information on African Parks' approach to community development, see: https://www.africanparks.org/our-work/community-development
86. African Parks: https://www.africanparks.org/our-work/community-development
87. EarthRanger: https://earthranger.com/Technology.aspx
88. Vulcan: https://vulcan.com

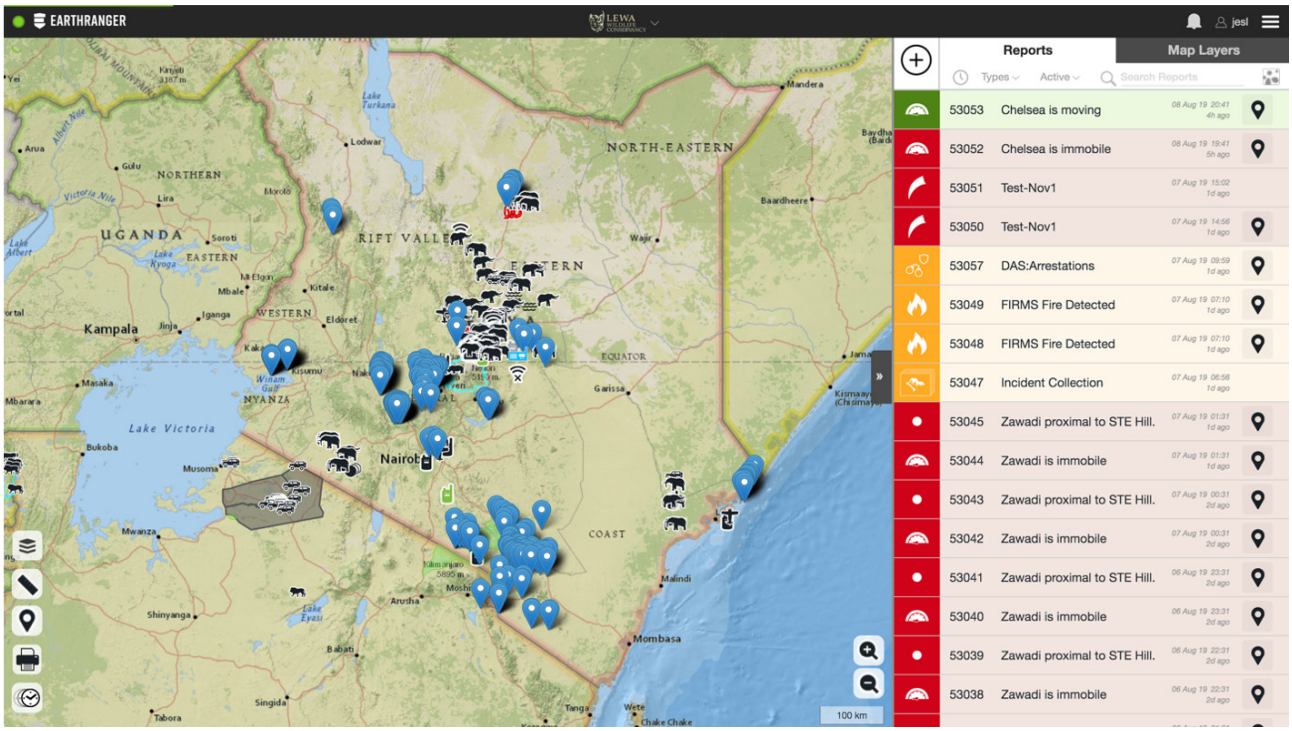


Photo courtesy of Vulcan Inc.

EarthRanger was designed to be intuitive and highly visual, which reduces the amount of time that African Parks and other users must dedicate to training new rangers or park managers to use the software. In 2019, Vulcan announced a new partnership with the Southern African Wildlife College (SAWC) to offer EarthRanger deployment, configuration and support services at local rates to wildlife reserves, protected area managers and staff.[89] It also allows the SAWC to include EarthRanger as part of their training curriculum, providing an increasing number of future conservation professionals with the ability to implement EarthRanger as part of their work.

At Liwonde National Park in Malawi, which is managed in partnership with African Parks, EarthRanger is helping to reduce human-wildlife conflict caused by dense populations of elephants that often raid crops and degrade local ecosystems. The system allows rangers to intervene before elephants reach local farms and tensions escalate with community members,[90] preventing human and animal deaths and helping farmers generate better crop yields and receive higher prices. EarthRanger has also played a role in the broader transformation of the park: in the four years since African Parks began managing Liwonde, the ranger force has developed into one of the best in Southern Africa; over 36,000 wire snares have been located and removed, and it has orchestrated historic reintroductions of animal species, including lions and cheetahs.[91]

For more information, see: africanparks.org or vulcan.com

89. EarthRanger (4 December 2019), Southern African Wildlife College and EarthRanger Announce Partnership.
90. See: https://earthranger.com/Success-Stories/Liwonde.aspx
91. Smart Park Liwonde: https://www.smartparks.org/projects/smart-park-liwonde-malawi/

Case study 3: **Restoring mangroves**

MANGROVES IN CONTEXT

Although they make up less than one percent of all tropical forests, mangroves form some of the world's most valuable coastal ecosystems and play a vital role in sustaining biodiversity, supporting coastal communities and mitigating the impacts of climate change. Coastal mangroves' tangled webs of submerged and above-ground roots protect land from eroding waves, provide essential habitats for thousands of animal species and create nurseries for young marine life until they are able to move to adjoining coral reefs or the open sea. A recent study in Kenya found that nearly 40 per cent of the value of all fish caught off the country's coast were mangrove-dependent species.[92]

The vast majority of people living in close proximity to mangrove forests are in Asia and West and Central Africa,[93] and according to the FAO, it is typically the poorest and most vulnerable coastal communities that benefit most from mangrove products and services.[94] Low-income communities are most likely to depend on mangrove forests for their livelihoods (e.g. small-scale fishing) and as a regular source of animal protein, clean water and timber for construction or fuel. Mangroves also reduce the loss of income and property in local communities by providing a natural defence against extreme weather events and disasters. They are uniquely adept at dampening waves, reducing the force of wind and floodwaters and distributing sediment across shorelines, offering a nature-based solution that can outperform hard (human-made) infrastructures and adapt to sea level rises or land subsidence in ways that engineered defences cannot.[95]

Mangrove forests, as well as other "blue carbon" ecosystems like seagrass beds and tidal marshes, are also among the most intense and proficient carbon sinks on the planet.[96] Recent studies have shown that mangrove forests are extraordinary long-term carbon sinks, storing up to 50 times more carbon per hectare than tropical rainforests.[97] Mangroves also offer a more secure form of carbon sequestration, as they are seldom threatened by forest fires and store carbon deep within their root systems and neighbouring soil, rather than in their trunks or branches. It is estimated that 20 billion tonnes of carbon are stored in the world's mangrove forests, which is roughly 2.5 times current annual global greenhouse gas emissions.[98]

92. FAO, Valuing Coastal Ecosystems as Economic Assets.
93. UNEP, The Importance of Mangroves to People: A Call to Action.
94. FAO, Valuing Coastal Ecosystems as Economic Assets.
95. Schueler, K. (2017), Nature-Based Solutions to Enhance Coastal Resilience. Inter-American Development Bank.
96. UN (2017), The Ocean Conference.
97. UNFCCC, "Sri Lanka Mangrove Conservation Project".
98. *Ibid.*
99. Wertz-Kanounnikoff, S. and V. Agostini (23 July 2019), International Day for the Conservation of the Mangrove Ecosystem: Why and How We Need to Save Mangroves. IISD / SDG Knowledge Hub.

MANGROVES IN CONTEXT

Because mangroves offer such wide-ranging environmental and social benefits, policymakers are increasingly investing in their conservation and restoration as a natural solution to meet the SDGs and international greenhouse gas commitments. In fact, at least 45 countries specifically mention mangroves in their national plans to tackle climate change, 28 countries mention mangroves in their restoration pledges and as many as 62 countries have named them in their national biodiversity plans.[99] Even so, mangroves remain severely threatened, and over the past 50 years the world has lost half its mangrove forests, mostly due to changes in land use for agriculture or coastal development, deforestation for fuelwood and charcoal production, and pollution from discarded plastics and other sources.

Restoring mangroves: Ericsson

In Malaysia, NGO estimates suggest that only 40 per cent of mangrove seedlings are able to reach maturity due to the impacts of climate change, pollution and intrusion from both humans and wildlife.[100] In recent years, the country has experienced longer than usual dry seasons, followed by seasons of intense rain characterised by widespread flooding. This, combined with the deforestation of large areas of mangrove forests, has caused erosion along riverbanks and left coastal communities vulnerable to income shocks and natural disasters like floods and tsunamis.

In response to this challenge, Ericsson Malaysia launched the Connected Mangroves project—a first of its kind reforestation project that leverages connected technologies to enable communities and non-profit conservation organisations to collect and visualise critical data on growing mangroves. The project is delivered in collaboration with the Global Environment Centre (GEC), local community organisations, technology sensor partner Luimewah Sdn Bhd and connectivity by the telecommunications services company Celcom (a subsidiary of Axiata Group).[101]

The project was initiated in 2015 in the coastal community of Kampung Dato Hormat where local villagers were working to restore their dwindling mangrove forest cover, but were unable to get more than 30 per cent of the planted saplings to survive to maturity.[102] At the launch of the project, volunteers from Ericsson and their NGO partners helped members of the local community plant mangrove saplings, and equipped the project site with low-cost, waterproof sensors. Each sensor is powered by small solar panels and can measure the environmental conditions affecting the health of up to 200 mangroves (covering roughly 2,500 square metres), including soil moisture, humidity, water levels and temperature, and any animal intruders (such as monkeys). Time-lapse cameras have also been installed to remotely capture footage from the restored plantations.

100. UNFCCC, "Connected Mangroves – Malaysia".
101. Ericsson (28 March 2019), "Ericsson and edotco Malaysia partner to grow 'Connected Mangroves' project in Kampung Dato Hormat, Sabak Bernam, Selangor". Press Release.
102. Ericsson (21 April 2017), "Celebrating Earth Day with our growing mangrove trees in Malaysia", Ericsson Blog.

This information is compiled and transmitted to a cloud-based server in real time, populating a digital dashboard that is accessible to the local community, NGOs, academics and other local authorities on any device with an internet connection.[103] The web-based dashboard can be customised for any of the project's key stakeholders, and Ericsson has defined data thresholds (e.g. low soil moisture, water level and condition, temperature or animal intrusions) that trigger instant alerts to relevant members of the community so they can respond appropriately. By constantly improving the quality and quantity of the data, the system is helping researchers identify new climate-related trends and develop mechanisms to improve the life of mangrove seedlings through improved irrigation, fertilisation or other methods.[104]

The use of sensors and a web-based dashboard in the Connected Mangroves project has allowed the local community to understand which environmental conditions are influencing survival rates, and has also helped them adjust the plant and soil conditions to be more conducive to healthy growth. As a result, Ericsson has seen survival and growth rates soar to 80 per cent in the project site.[105] Since the start of the project, Ericsson and its partners have helped plant 3,400 mangrove saplings in Malaysia, most of which have now grown to a height of six feet or more.[106]

In 2017, the project was replicated successfully in the Philippines in partnership with MNO Smart Communications, and the project's beneficiary community has already reported improved fish catches in the surrounding area and the presence of migratory birds that have been not seen for over seven decades.[107] Local authorities have also noted that community well-being has improved since the installation of the sensors; there is greater flood protection, and local fishers—who can face up to 20 typhoons each year—have been able to improve their livelihoods by monitoring water conditions before they set out to catch fish.[108] Furthermore, the NGOs driving mangrove reforestation initiatives are now able to leverage the digital technology to increase their impact, make their programmes more transparent and provide better support to the community.[109]

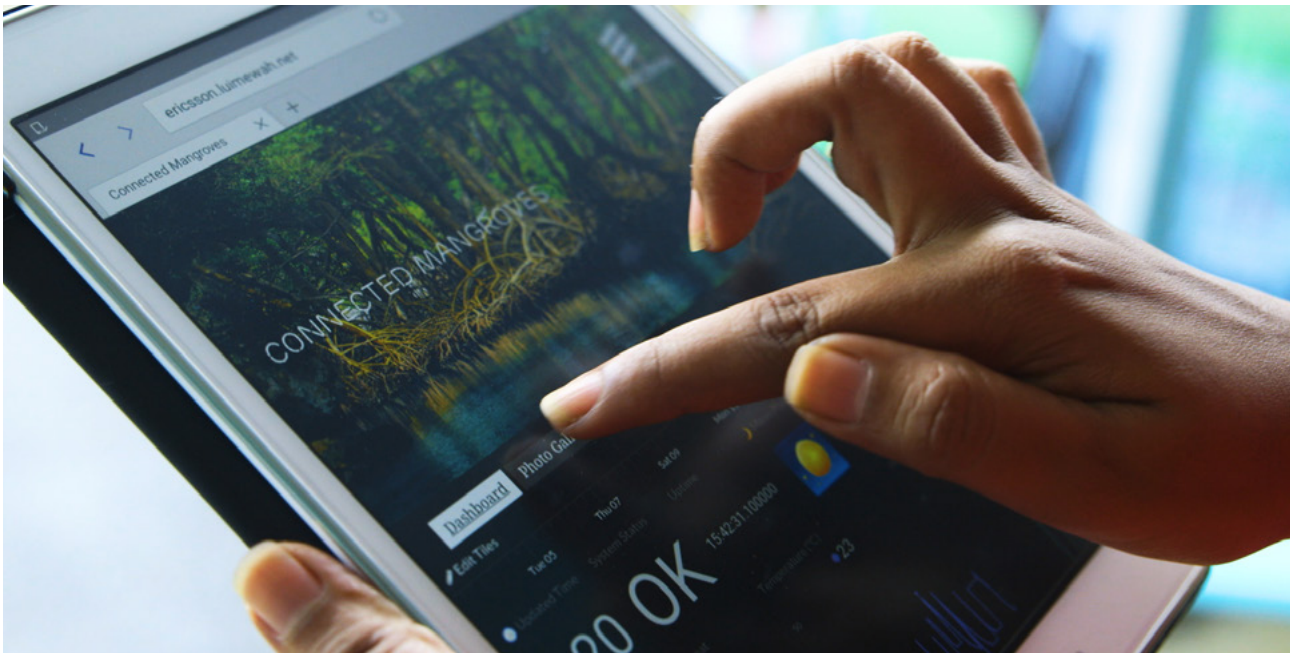
The connected devices used by Ericsson in each market are widely available at a reasonable price, making it easier to replicate and scale their activities. Ericsson also uses 3G/4G wireless networks to capture and transmit data, which has high global coverage and can enable low-cost communication between the sensors and the cloud. By working with local technology providers and communities, the development, installation and maintenance of the sensors has also become more sustainable. For instance, local community chiefs have taken on responsibility for using the data to maintain and increase the survival rate of the plants. Ericsson also believes that the same approaches and technologies could be applied to other crops, aquaculture or even specific areas like fisheries without having to make significant changes, providing even more opportunities for scale.[110]

103. UNFCCC, "Connected Mangroves – Malaysia".
104. *Ibid.*
105. Ericsson (21 April 2017), "Celebrating Earth Day with our growing mangrove trees in Malaysia", Ericsson Blog.
106. Alarilla, E. (7 October 2019), "Latest from the Connected Mangroves reforestation project", Ericsson Blog.
107. *Ibid.*
108. *Ibid.*
109. UNFCCC, "Connected Mangroves – Malaysia".
110. *Ibid.*

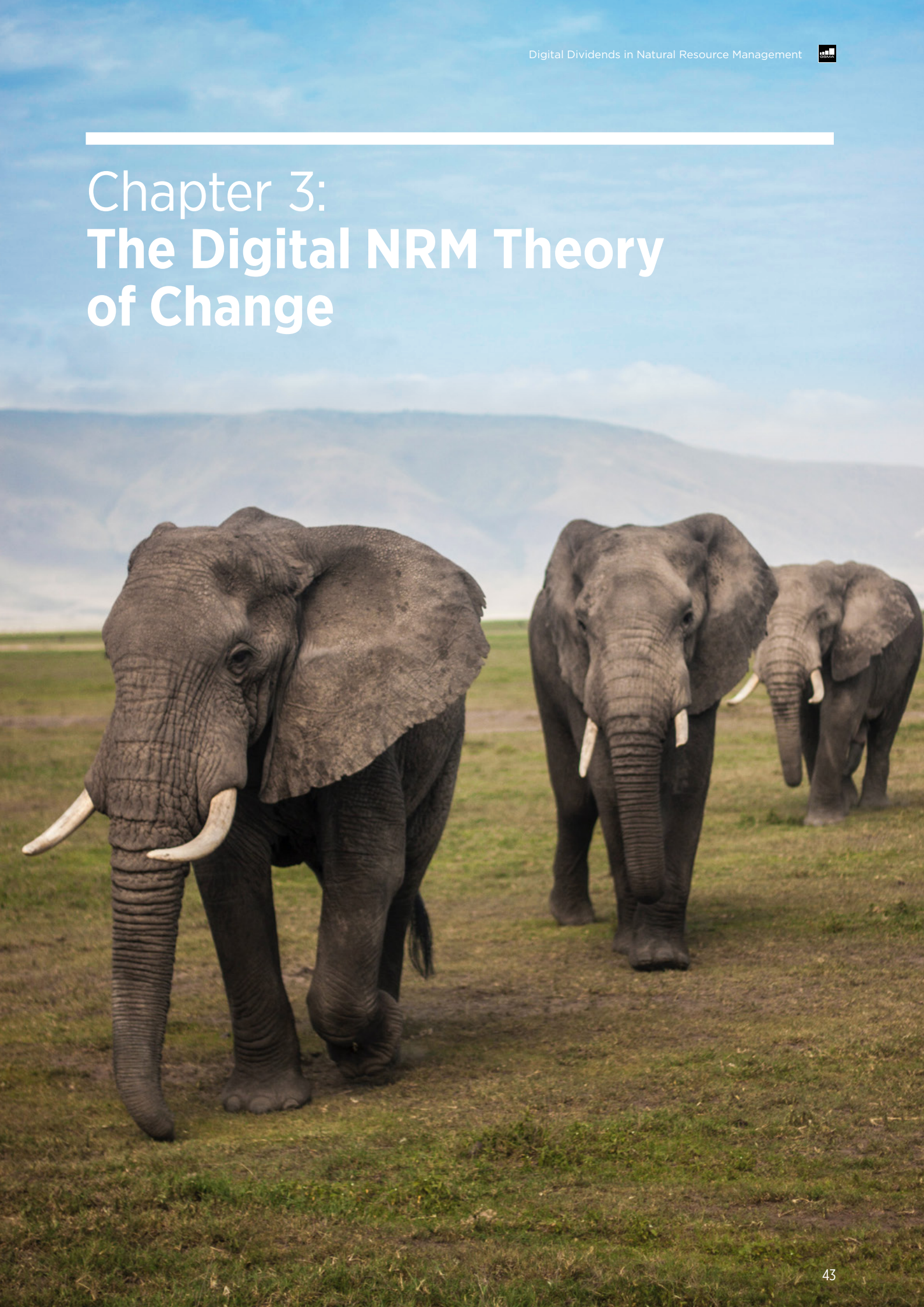
Right: *one of the solar-powered sensors among mangroves (photos courtesy of Ericsson);*

Bottom: *the Connected Mangroves dashboard*

For more information, see: ericsson.com



Chapter 3:
The Digital NRM Theory of Change



Our desk research and stakeholder interviews indicate that five key stakeholder groups are shaping the digital NRM landscape (outlined on the following pages). On a project-by-project basis, the role that each stakeholder group plays, and the degree to which they influence or control NRM activities, is highly variable and typically depends on the operating or partnership model, the regional or local context, the technical skills or funding required and the project's lead organisation, among other factors.

These stakeholder groups also tend to contribute at varying stages in the NRM project lifecycle, from funding and planning to governance, project delivery and implementation. Each stakeholder group is likely to encounter different challenges, opportunities and benefits when engaging with digital solutions, helping to enable use of technology and digital approaches for NRM, or creating barriers that slow the adoption rate and scalability of digital solutions.

Interviews were conducted with over 30 experts from these stakeholder groups (excluding government) to test and validate emerging insights from desk research and the NRM Heatmap, and to identify the specific incentives, bottlenecks, preferences and benefits that stakeholders of NRM projects encounter when engaging with digital systems or services. These can be summarised as follows:

Providers of capital and funding: In addition to private donors, conservation finance organisations (including carbon offset funds) and private sector foundations, NRM activities have traditionally fallen under the remit of agencies that assist developing countries in implementing environmentally sound policies and practices; this includes the FAO,[111] UNEP[112] and UN-REDD.[113] In recent years, a number of international aid organisations have recognised that "sustainable environmental stewardship…helps build healthier populations, preserve livelihoods, and create new economic opportunities"[114], which has led to a growing number of digital initiatives being funded and delivered with support from DFID,[115] USAID[116] and the World Bank.[117]

New partnerships between donors and NRM organisations are helping to address the common causes of environmental degradation and poverty, with donors seeking to work collaboratively with other project stakeholders to contextualise NRM challenges and determine the most appropriate digital solution or approach. Donors might be cautious about putting too much attention or resources into new or emerging technologies and are averse to "overhyping" their potential, and may prefer to focus on helping organisations scale or use established technology more effectively. Benefiting from years of experience and extensive research programmes, donors are likely to be well-versed in both the opportunities and pitfalls related to the use of digital technology, but are still keen to engage with technology companies that can help build their capacity to keep pace with digital innovation.

111. FAO (8 October 2019), Countering climate change with innovation.
112. UNEP, "Technology".
113. The United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation; see: https://www.un-redd.org/forest-facts
114. USAID, Environmental and Natural Resource Management Framework.
115. DFID (23 September 2019), UK to double efforts to tackle climate change.
116. USAID, Environmental and Natural Resource Management Framework.
117. World Bank (12 May 2016), Innovation Centers Help Developing Countries Capture Climate Change Opportunities.

Governments: The responsibility for funding and governing natural resources often falls under the remit of national or local government ministries, or even military departments (in the case of counter-poaching and other law enforcement activities). These institutions are increasingly receiving financial and technical support from international donors, the private sector and development organisations as they set and deliver NRM objectives or strategies. Digitising the NRM sector is broadly viewed as positive, as it can create benefits for the economy and adjacent sectors (such as tourism) while also contributing to digital transformation schemes and the SDGs. In some cases, NRM organisations can create "peace dividends" for governments by bringing stability to protected areas, and they might also fill a gap in government service provision. African Parks, for instance, builds support for their parks by investing in local infrastructure, enabling better access to health care and education and contributing to local livelihoods.[118]

While there has historically been little political will for bottom-up approaches to NRM, there are signs this is changing, especially in remote areas where the government lacks the resources or ability to manage resources effectively. Government participation is viewed as positive for other NRM stakeholders, as it often provides new sources of funding and other benefits that can strengthen the case for MNOs and other technology organisations to participate.

NRM organisations: This category includes a diverse range of global and local organisations with a mission to generate positive environmental impact, although many have seen their remit expand to socioeconomic outcomes. The NRM organisations engaged through our research were all non-profit, but our project list also includes numerous examples of social enterprises that are entering this space and applying commercial strategies to their environmental and social mission. NRM organisations, including many social enterprises, still appear to fund the majority of their activities through philanthropic or donor funding, and are most often the lead organisation in NRM projects. Pressure to remain competitive for future grants, and the desire to drive innovation, has led many organisations to invest in digital approaches and many are incredibly tech savvy.

However, gaps in funding and technical expertise persist, even in global organisations. Stakeholders engaged through our research were interested in exploring opportunities to raise awareness and market the benefits of NRM to citizens and other stakeholders; to find ways to integrate NRM with the broader sustainable development agenda; to learn from, or replicate the success of other digital projects; and to forge new shared-value partnerships with the private sector. Working with technology organisations to address digital skills gaps is viewed as an extremely valuable contribution, with some organisations suggesting this in-kind support is more valuable than project funding. Participatory approaches to NRM are becoming a priority for many NRM organisations, but some are finding that low digital skills among local delivery partners and community members are threatening the long-term sustainability of these efforts.

118. African Parks: https://www.africanparks.org/our-work/community-development

Digital technology organisations: In the context of this study, this category includes MNOs and other companies in the broader mobile ecosystem, including handset and device makers, software companies, equipment providers and internet companies. NRM remains a nascent topic within the sector, but MNOs in LMICs have decades of relevant experience applying GSM and wireless technologies to address socioeconomic disparities, and an intimate, tacit knowledge of and affinity with local communities. For this reason, governments and NRM organisations are highly motivated to explore partnership opportunities, but many organisations lack the experience necessary to know where to engage or how to identify the right partners.

Projects that incorporate emerging technologies, such as IoT and AI, are resource-intensive and highly complex, but according to the GSMA, we are entering an era in which MNOs are investing in innovative solutions across big data, machine learning, analytics, edge computing and distributed ledger technologies, and many are beginning to shift from being providers of connectivity to providers of IoT platforms, applications and services.[119]

Creating sustainable business models for the provision of NRM services remains a challenge at this early stage, but projects led by CSR and sustainability functions are helping firms incubate and refine new technologies and approaches, which in turn is deepening their understanding of the market. The World Wide Fund for Nature (WWF) has also found there is a significant change in the way millennial consumers think about business, with 47 per cent believing that the purpose of a business is to improve society and protect the environment.[120] As they describe it, "this is a fundamental sea change in the way an entire generation thinks about business… if you want to attract the top talent and retain them, if you want to win over customers, you have to have a narrative around how your products are sustainable and healthy, and you have to have an impact story."

Citizens and local community members: While this term encompasses a group of interacting people who live in a common location, it is important to remember that local communities represent a diverse set of needs, goals and perspectives. In the context of this study, the local community may be those who stand to benefit from, and may actively participate in NRM activities, as well as community-based organisations that engage in projects and act as trusted intermediaries between the community and other NRM stakeholders. In recent years, there has been greater recognition that local knowledge, participation and buy in are crucial to the success of NRM efforts, and therefore greater emphasis on including them in activities and decision making. Engaging with local communities and civil society organisations at the start of any project is viewed as an effective way to avoid negative outcomes, to build trust and cooperation between project stakeholders, and to ensure that digital services and platforms are built with community needs and digital capabilities in mind.

119. GSMA, "Internet of Things".
120. WWF video: Our Planet: Our Business.

The Digital NRM Theory of Change

Insights collected on each of the key stakeholder groups were used to develop the Digital NRM Theory of Change, which captures the causal links between the three main categories of digital technology use—enabling real-time monitoring and data collection; supporting community engagement in NRM activities; and allowing organisations to store, analyse and visualise data—and subsequent stakeholder outcomes. The outcomes generated by providers of capital, including government donors, are assumed to be part of the material outcomes of the other four key stakeholder groups and are therefore not captured separately. This Theory of Change is high level and generic, and intended to provide a useful reference point for identifying key outcomes and insights experienced by each major stakeholder group when deploying digital technology. However, these will need to be refined when applied at an individual project level.

The assumptions underpinning the Theory of Change comprise enablers generally under the control of an organisation or stakeholder group, as well as externalities and challenges that affect an organisation's or stakeholder's ability to achieve the desired outcomes. Enablers are often characterised by the mechanisms that help an organisation or stakeholder group to deliver on planned activities, and are closely linked to the sustainability of an NRM project. Externalities, in contrast, are best described as social, cultural, economic and political factors, laws and regulations that need to be strategically managed to mitigate barriers and potential adverse outcomes. A balanced Theory of Change is also a useful tool for assessing causal outcome pathways that may lead to unintended and unfavourable outcomes for stakeholders. We have identified these unintended outcome pathways as indicative risks that need to be considered and factored into project design, planning and mitigation strategies. During our stakeholder discussions, there were calls to pay attention to these types of challenges and the need for awareness and appropriate safeguards to mitigate risks, such as having trusted intermediaries. Intended positive outcomes, however, significantly outweigh unintended outcomes.

As an additional step, we have mapped the potential long-term impacts and correlation of overall impacts arising from digital approaches to the SDGs based on assumptions and stakeholder feedback. We identified 10 SDGs likely to be impacted through digital interventions, the most common of which were SDG 1 (No Poverty), SDG 8 (Decent Work and Economic Growth), SDG 13 (Climate Action), SDG 14 (Life Below Water), SDG 15 (Life on Land) and SDG 17 (Partnerships for the Goals). It should be noted that while digital approaches could improve development outcomes more broadly across all 17 SDGs, the other seven were not the focus of this research. Equally, tangential links to gender equality can be made, but would depend on the ways in which specific interventions are implemented.

Digital Dividends in Natural Resource Management

Figure 5

Theory of Change results chain from NRM use cases to outcomes and impacts

Key stakeholders

NRM organisations	Digital technology organisations	Local communities		Government	Providers of capital and funding
Global/local non-profit organisations Social enterprises Privately-owned nature reserves NRM speciality services organisations	MNOs Handset and device makers Software Companies Equipment Providers Internet Companies	Citizens Community Organisations or Cooperatives	Civil Society Organisations	National and Local Government Environment Ministries Government Defence Departments Telecommunications Regulators	Private Donors Conservation Finance Organisations Private-Sector Foundations International Environmental Agencies International Development Organisations

Activity to address the need/opportunity – use case >>> Technology enables the output >>> Resulting in improved outcomes for a diverse group of stakeholders >>>

Impact pathways

NRM USE CASE – ACTIVITY

CATEGORY 1: Technologies and connected devices for real-time monitoring and data collection

Use case 1: Bespoke data collection using connected devices, such as camera traps, drones and sensors to support NRM decision making

Use case 2: Use of technologies to reduce harmful activities, such as wildlife poaching, illegal fishing, illegal logging or ocean pollution

CATEGORY 2: Technologies for community engagement in NRM

Use case 3: Use of technologies to influence positive behaviour change and community engagement in NRM activities, such as supporting reforestation

Use case 4: Provision of tools and solutions to local communities to improve NRM procedures, governance and planning

Use case 5: Payment for ecosystem services using mobile payment platforms to incentivise communities to support NRM objectives

CATEGORY 3: Technologies for data storage, visualisation and analysis

Use case 6: Use of AI and data visualisation tools to aid decision making and support better NRM outcomes

MATERIAL OUTCOMES BY STAKEHOLDER GROUP

NRM organisations

- Percentage increase in success rate of NRM and (in some cases) socioeconomic development metrics
- Improved tech-related skills and capabilities
- Improved safety of personnel
- Misuse of data or technology that leads to harm**

Digital technology organisations

- Increase in commercial viability of using technology for NRM objectives
- Improved brand affinity and relationships with stakeholders

Local communities

- Improved awareness and understanding of NRM challenges, risks and costs
- Improved access to natural resources
- Improved engagement in NRM processes and decision making
- Improved livelihoods, well-being, and safety
- Improved resilience of communities to climate changes or hazards
- Displacement of community incomes **
- Threat of retaliation due to data breaches **

Government

- Increase in funding for NRM projects from international donors
- Improved governance and reduced (displaced) corruption
- Improved evidence-based performance against SDG and environmental targets
- Improved outcomes for adjacent sectors (e.g. to)

***Negative**/ unintended outcomes*

IMPACTS

- **Forest cover loss is mitigated and reversed**
  SDG: 1, 13, 15, 17
- **Protected terrestrial and marine species numbers recover**
  SDG: 13, 14, 15, 17
- **Sustainable social, economic and environmental co-benefits are realised**
  SDG: 1, 3, 8, 10, 13, 14, 15, 17
- **Community safety and engagement of stakeholder groups improved**
  SDG: 3, 8, 17
- **Environmental justice and equitable distribution of resources restored**
  SDG: 1, 13, 14, 15, 16, 17
- **Commercial viability and sustainable business models created**
  SDG: 9, 13, 14, 15, 17

Key challenges

NRM USE CASE – ACTIVITY

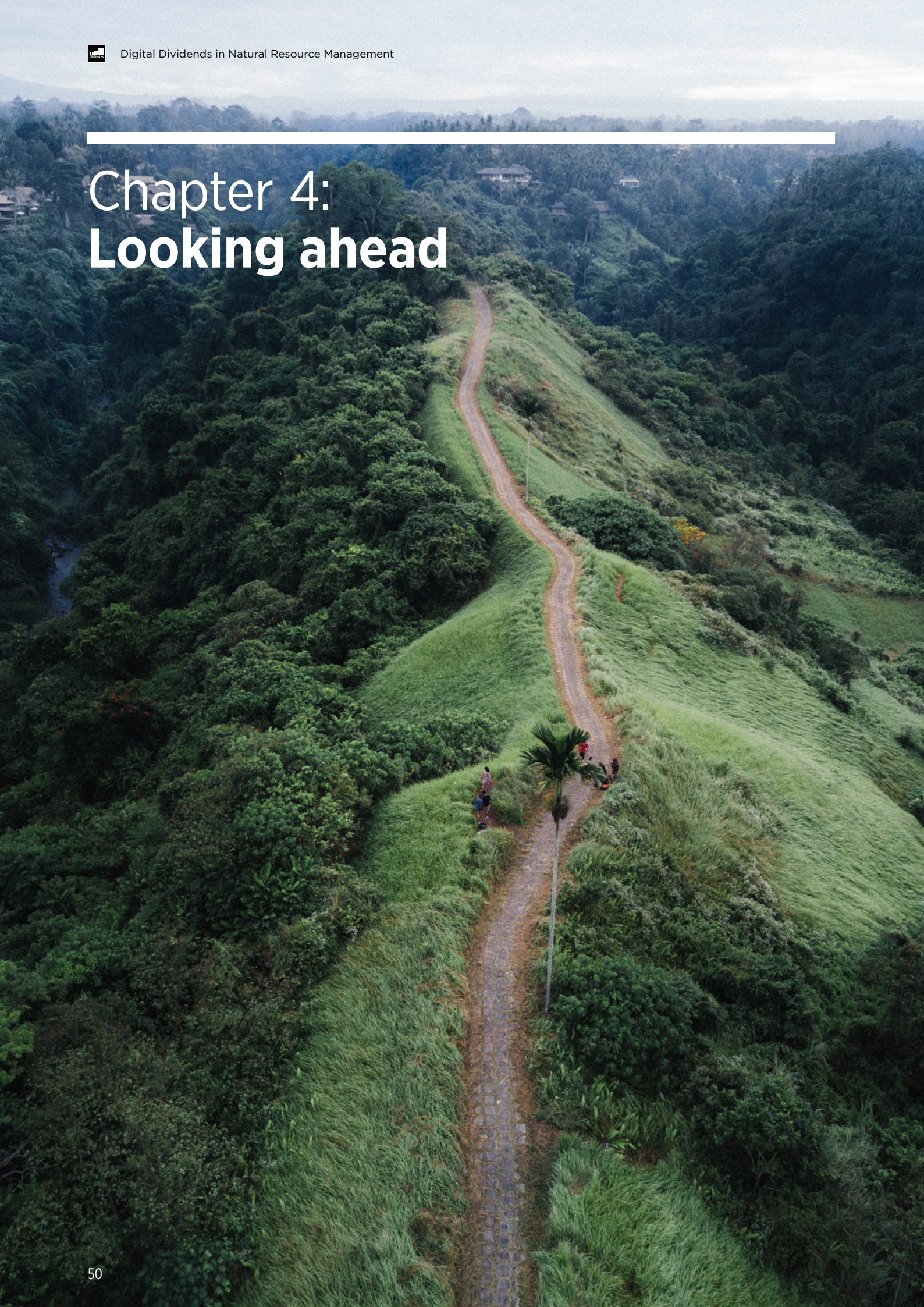
1. Nascent ecosystem of NRM stakeholders, including NRM organisations, digital technology organisations, local communities and government.
2. Investment constraints and evolving MNO business case to support NRM use cases.
3. Access and affordability of connectivity in remote locations remains challenging as GSM networks are still underrepresented in remote locations where NRM projects are implemented.
4. Natural resources in low population areas makes community benefits challenging to demonstrate, limiting (donor) resources that require human-centred returns.
5. Sustainability and scalability of projects are largely unproven.
6. Performance metrics associated with aid and capital expenditure vary and do not always align with NRM activities.

Key enablers

MATERIAL OUTCOMES BY STAKEHOLDER GROUP

1. Successful partnerships leverage stakeholder strengths and core competencies to deliver NRM outcomes in addition to long-term development impacts.
2. Involving and building the capacity of local community members and groups can lead to more sustainable and scalable NRM.
3. Low-cost network connectivity can allow a range of real-time data collection tools to be deployed by those managing and dependent upon natural resources.
4. Emerging technologies, such as IoT and AI, may provide viable business cases for MNOs, whereby sensors are used as a proxy for live connections.
5. Strong political will for improved NRM and an enabling regulatory environment.

Chapter 4:
Looking ahead



In the coming years, as the environmental crisis becomes even more complex and far-reaching, digital technology will play an increasingly critical role in protecting livelihoods and the natural resources on which they depend.

Our analysis of existing projects and conversations with stakeholders suggests there are two impact areas where further support could help mature and mainstream digital innovation in this sector. First, further research and insights are required to reveal and promote examples of best practice, to help technology organisations develop sustainable business and partnership models, and to empower underserved populations to play a more active role in NRM. Second, there is potential for new cross-sector partnerships and dialogue within and across stakeholder groups to catalyse new action. These opportunity areas are discussed in more detail below, and three high-level opportunities have been included to illustrate the potential outputs of collaborative action in the digital NRM space.

Impact Area A: Supporting NRM through research, toolkits and guidance series

While this report has provided a broad view of global trends and stakeholder perspectives, there are further opportunities to build on these insights through additional research that is more narrowly focused and contextually specific. Many of the organisations engaged in our project recognised a need for more human-centred design research that explores how specific NRM technologies or activities could be shaped by community members' and stakeholders' preferences, biases, capabilities and needs. Employing human-centred approaches has many benefits: it helps ensure that future projects are grounded in reality and have community interests at heart; it provides project implementers with a richer understanding of the social and political contexts in which they operate; and it can help prevent the inadvertent exclusion of vulnerable citizens, including women, the elderly, those with disabilities and others with low digital accessibility or literacy, in programme design. These approaches can also identify ways for digital technology to complement or work within traditional, customary NRM systems and process rather than imposing new ones, and support communities' understanding of technology and how it can benefit them.

Among the technology organisations engaged in our research, there were multiple requests to support the development of sustainable business and partnership models, given that the commercial case for participation can be a prohibitive issue for private sector organisations in LMICs with limited experience in this sector. There is also high demand for research that showcases additional examples of best practice in the mobile industry, or provides a deeper understanding of the partnership needs or motivations of local NRM stakeholders, especially government and local technology suppliers.

All NRM stakeholders saw value in the development of guidance series or toolkits that explore specific types of technology or NRM activities, with particular interest in connected devices and AI. Toolkits could also be designed to support organisations as they investigate how to develop NRM mobile applications that can be accessed by people without smartphones, how to implement and incentivise payments for ecosystem services, and how to create better mobile tools that push relevant NRM and livelihood information to local communities.

OPPORTUNITY 1: OPEN SOURCE AI TOOLKITS

The resources and technical expertise required to develop and apply AI algorithms are a significant barrier for many NRM organisations. Stakeholder interviews suggest that creating a suite of open source AI tools and codes for the NRM sector could provide a way for technology organisations to help drive broader adoption of AI, and transform the way that data is analysed and used. An Open Source AI Toolkit would offer core algorithms and generic design architectures for various NRM use cases, allowing organisations with limited capacity or expertise to leapfrog many of the design steps and overcome many of the challenges associated with AI adoption curves. Experts predicted that the toolkits could help NRM organisations get "90 per cent of the way" to developing the specific algorithms needed to deliver their projects, while also letting developers see how data is being used by the NRM community. To support this effort, the GSMA could engage with a community of AI subject matter experts, MNO representatives, donors and a small number of other NRM stakeholders to define the business case for open AI toolkits (to resolve any commercial or intellectual property risks), identify the most relevant use cases and begin developing proof of concepts.

Impact Area B: Facilitating new partnerships, sparking conversations and inspiring action

Organisations from every stakeholder group in our study described the challenges they have identifying and connecting with new partners in the NRM sector, whether they are seeking to develop new products or services, or looking for opportunities to replicate or scale existing projects. In many of our interviews we found that organisations were relatively unaware of the perceptions, motivations and needs of other stakeholder groups, and invited support to help inform and facilitate conversations that could catalyse new partnerships. The project's multi-stakeholder interviews were a useful way to test the value of convening stakeholders with similar objectives and complementary skills, and we found that participants were highly motivated to share lessons from their initiatives, to identify potential synergies and to imagine new ways of working together. In particular, multi-stakeholder conversations were helpful in revealing opportunities for cross-sector collaborations that could help address funding, skills and technology gaps.

In addition to working across sectors, MNOs and technology organisations were interested in working together to find new ways to address NRM challenges as an industry. MNOs would like to learn from successful NRM initiatives that are led or supported by their peers, and they recognise a need to collectively tackle issues that are barriers to NRM activities, such as the connectivity challenges prevalent in hard-to-reach areas. Partnerships with NRM organisations and governments are widely seen as beneficial, even when led by CSR or sustainability functions, as they provide firms with the opportunity to engage with new customers, incubate and refine the application of new and existing technologies, and deepen their understanding of the market.

OPPORTUNITY 2: SUPPORTING PES SCHEMES THROUGH DIGITISATION

Payment for ecosystem services (PES) schemes are notoriously difficult to deliver and typically fail to achieve scale. However, there was consensus among stakeholders that digital technology could play a crucial role in the monitoring, communication and payment processes essential to the success of PES schemes. There is an opportunity for MNOs and other technology organisations to work with NRM organisations to support the design and delivery of new PES schemes. Collaboration on human-centred research could inform contextually specific PES incentive models, helping to encourage and fairly reward community participation. The high uptake of mobile money services in low and middle-income countries, particularly among segments of society targeted by PES schemes, suggests that opportunities for collaboration with MNOs would be extremely valuable. Mobile money services provided by MNOs and other mobile money providers could offer a more convenient, cost-effective and transparent way for organisations to transfer entitlements to beneficiaries and ensure that both financial and non-financial benefits reach all the individuals responsible for the project's success. In addition, technology organisations could be leveraged to provide the tools and expertise required to help organisations develop their own data collection tools and analysis capabilities, which is likely to be a prerequisite for implementing PES schemes.

OPPORTUNITY 3: SCALING THE USE OF IOT FOR NRM USE-CASES

MNO stakeholders have described the Internet of Things (IoT) as a key part of their long-term operating strategy, yet for many NRM organisations the cost and skills required to deploy connected devices remains a key barrier to uptake and scale. While the devices used for high-frequency use cases are becoming widely available, those used for less common NRM activities are typically produced in low volumes, preventing the market from benefiting from economies of scale. Several MNOs and technology organisations said they were eager to replicate or scale the success of existing IoT projects, while other organisations expressed interest in forging new partnerships. These activities would support local IoT ecosystems by multiplying the number of devices in the market, and by incentivising MNOs to invest in expanding connectivity in low population areas (as the connected devices would act as a proxy for connected people).

Looking ahead

With the UN estimating that the global community has just one decade left to change direction, ambitious and urgent action and a renewed commitment to working in partnership will be critical to achieving the 2030 climate agenda and protecting decades of development progress. As the international community develops new strategies to mitigate and respond to the impacts of our environmental crisis, such as more frequent extreme weather events, reductions in wildlife and biodiversity, sea level rises and the daily loss of temperate rainforests, it is clear that digital technologies will play a critical role. Our research has helped create a more comprehensive picture of global trends and innovation in the NRM sector, as well as the common incentives, bottlenecks and benefits encountered by NRM stakeholders when deploying digital technology. We are excited to see that as this sector matures, there will be many opportunities for MNOs and other technology organisations to leverage their resources and technical expertise to make emerging technologies more accessible to, and impactful for, a wide range of NRM stakeholders. In doing so, they will help scale nature-based solutions to climate action, reduce biodiversity loss, optimise nature's contribution to resilient livelihoods and bring long-term value to their organisation.

Appendices

Appendix A: Heatmap

	NRM ACTIVITY / TECHNOLOGY TYPE	SOFTWARE									DEVICES					CONNEC-TIVITY		
		Call Centres	Interactive Content	Peer-to-Peer Content	Push and Pull Content	Inventory Management Tools	Mobile Payments	Artificial Intelligence	Data Visualisation	Block -chain	Mobile Devices	Niche Devices	Drones	Satellite	Sensors	Network Infrastructure	Network Software	
SUPPORTING LIFE ON LAND	Forest Management	0	0	1	4	2	0	6	16	3	1	1	5	9	7	0	0	55
	Securing Land Rights	0	1	0	2	1	0	0	10	6	1	0	4	01	0	0	1	27
	Wetland Management	0	0	0	1	0	0	0	1	0	0	0	1	1	1	0	0	5
	Invasive Species and Disease Control	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2
	Grasslands	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
	Wildlife Counter-Poaching	0	0	0	3	0	0	7	11	1	0	3	4	3	7	2	0	41
	Wildlife Species Preservation	0	0	0	2	0	0	5	7	0	1	1	1	3	8	1	2	31
	Wildlife tracking	0	3	0	5	0	0	0	8	0	0	0	0	0	0	0	0	16
	Preventing Human-Wildlife Conflict	1	0	0	2	0	0	0	3	0	0	0	0	1	3	0	0	10
	Wildlife Habitat Protection and Restoration	0	0	0	0	1	0	0	2	1	1	0	0	2	2	0	0	9
SUPPORTING LIFE BELOW WATER	Sustainable Fishing Practices	0	1	0	3	0	0	4	12	4	3	0	1	3	1	0	1	33
	Preventing and Cleaning Ocean Pollution	0	0	0	4	0	0	0	7	3	0	0	2	0	1	0	0	17
	Marine Counter-Poaching	0	0	0	0	0	0	1	1	0	0	0	6	1	0	0	0	9
	Marine Species Preservation	0	0	0	1	0	0	1	2	0	0	0	3	0	0	0	0	7
	Marine Habitat Protection and Restoration	0	0	0	0	0	0	0	1	1	0	1	1	0	1	0	0	5
OTHER ACTIVITES	Air Pollution Monitoring and Early Warning Systems	0	0	0	3	0	0	0	3	0	0	0	0	0	4	1	1	12
	Air Pollution Prevention	0	0	0	0	0	0	1	1	0	0	0	2	0	1	0	0	5
	Building Climate Resilience	0	0	0	1	0	0	0	1	0	0	0	2	0	1	0	0	5
	Drought Preparedness	0	0	0	0	0	1	0	1	0	0	0	0	2	0	0	0	4
	Water Catchment Management	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	3
		1	5	1	31	4	2	25	88	19	7	6	34	27	37	5	5	297

Appendix B: NRM activities and technology types

Table 1

NRM activities included in the heatmap

NRM category	NRM activities
Terrestrial use types: Supporting Life on Land	Forest Management, Securing Land Rights, Wetland Management, Invasive Species and Disease Control, Grasslands, Counter-Poaching, Wildlife Species Preservation, Wildlife Trafficking, Preventing Human-Wildlife Conflict, Wildlife Habitat Protection and Restoration
Marine use types: Supporting Life Below Water	Sustainable Fishing Practices, Preventing and Cleaning Ocean Pollution, Marine Counter-Poaching Activities, Marine Species Preservation, Marine Habitat Protection and Restoration
Other activitieshome	Air Pollution Monitoring and Early Warning Systems, Air Pollution Prevention, Building Climate Resilience, Drought Preparedness, Water Catchment Management

Table 2

Technology types included in the heatmap

Technology type		Definition
Software	Call Centres	Centralised department with which citizens can share information or make enquiries with relevant authorities.
	Interactive Content	Content that requires its consumers to actively participate and engage, rather than acting as a passive viewer or listener.
	Peer-to-Peer Content	The sharing of data, information, photos or other content between peer groups using two or more devices.
	Push and Pull Content	Push content refers to small messages delivered to relevant consumers without interaction from them. Pull content refers to data or information that users proactively seek out or submit to NRM organisations or authorities.
	Inventory Management Tools	Includes a suite of devices, systems and software for tracking inventory levels of various natural resources (e.g. forest cover or fish stocks).
	Mobile Payments	Digital transactions that use a mobile phone to transfer money and make or receive payments.
	Artificial Intelligence	Artificial Intelligence is the ability of a computer or machine to gain insights and enhance decision making through learning (e.g. machine learning or deep learning) and automation. This can include visual processing, prediction of outcomes, categorisation of objects or data and problem solving.
	Data Visualisation Tools	Tools and dashboards which provide low-cost, dynamic ways for NRM organisations and everyday citizens to discover, explore and derive insights from data.
	Blockchain	A database that exists across several locations or among multiple participants. Blockchain is a shared, immutable ledger that can be used for recording transactions, tracking assets and providing assurance.
Devices	Mobile Devices	A wireless handheld device that allows users to make and receive calls, send text messages and share and download data.
	Niche Devices	Devices that have distinct appeal to a small segment of the market. In the Heatmap this includes thermal cameras, underwater roving data collectors, radar and specified sensors.
	Drones	A drone is an unmanned aerial vehicle (UAV) with three key components: an airframe, a payload (e.g. a camera or sensors) and data analysis (e.g. flight mapping).
	Satellite	Machines that orbit the earth and provide a wide range of services, such as enabling two-way communication or providing observation imagery as a primary data source for monitoring weather, land cover or land change.
	Sensors	Devices connected to fixed or wireless internet to enable the collection and sharing of data, remotely and in near-real time. In a very broad sense, the term Internet of Things (IoT) encompasses all types of sensors and devices connected to the internet.
Connectivity	Network Infrastructure	An enterprise's entire collection of hardware, data centres, facilities and related equipment.
	Network Software	Software for the design and implementation of modern networks.

Appendix C:
NRM Project Listx

The 131 digital NRM projects identified through desk research and displayed in the NRM Heatmap are listed below. This is not intended to be an exhaustive record of all digital natural resource management projects currently being undertaken globally. However, the projects identified are illustrative of current trends in digital approaches to NRM.

	Programme name	Primary Tech	NRM Sector	Location	Link
1.	**Abalobi**	Mobile Handsets	Sustainable fishing practices	South Africa	http://www.fao.org/e-agriculture/news/abalobi-app-help-small-scale-fishermen-south-africa-monitor-catches
2.	**Aerial mangrove restoration**	Drones	Forest management	Myanmar	https://www.futuresplatform.com/blog/tree-planting-drones-could-save-us-deforestation-UAV-sustainability
3.	**Air Shepard**	Drones	Terrestrial anti-poaching activities	Malawi, Zimbabwe, South Africa	https://airshepherd.org/
4.	**B+WISER project, Philippines**	Mobile handsets	Terrestrial habitat protection and restoration	Philippines	https://www.chemonics.com/wp-content/uploads/2019/01/APPROVED_BWISER-Contract-Completion-Report-01242019.pdf
5.	**Bankokair pollution drones**	Drones	Air pollution prevention	Thailand	https://www.irishexaminer.com/breakingnews/world/bangkok-using-water-spraying-drones-and-planes-to-try-to-cut-air-pollution-901364.html
6.	**Belize illegal fishing drones**	Drones	Marine anti-poaching activities	Belize	http://divemagazine.co.uk/eco/6703-drones-fight-illegal-fishing-in-belize
7.	**Bitcoin against poaching**	Blockchain and distributed ledger	Terrestrial anti-poaching activities	Africa	https://www.pacifichashing.com/bitpos-and-international-anti-poaching-foundation-team-up-to-save-africas-animals/
8.	**Bitland**	Blockchain and distributed ledger	Securing Land Rights	West Africa and India	https://time.com/collection/genius-companies-2018/5412105/bitland/
9.	**Borneo forest use of drones programs**	Drones	Forest management	Borneo, (Indonesia)	https://observers.france24.com/en/20161007-drones-helping-save-forests-borneo-indonesia
10.	**BreezoMeter App**	Push notification & Pull content	Monitoring and early warning system for air pollution	India	https://breezometer.com/

Programme name		Primary Tech	NRM Sector	Location	Link
11.	**Cadasta Platform**	Mobile handsets	Securing Land Rights	Global	https://cadasta.org/about-us/
12.	**Care for the Uncared**	Blockchain and distributed ledger	Marine habitat protection and restoration	Uganda	https://www.investereum.com/2019/02/09/the-happy-blockchain-animals/
13.	**Chromaway - Andra Pradesh**	Blockchain and distributed ledger	Securing Land Rights	India	https://www.coindesk.com/andhra-pradesh-partners-with-chromaway-to-develop-blockchain-land-registry
14.	**Clean swell**	Push notification & Pull content	Preventing ocean pollution and promoting ocean clean-up	Global reach	https://oceanconservancy.org/trash-free-seas/international-coastal-cleanup/cleanswell/
15.	**Connected conservation**	Sensors	Terrestrial anti-poaching activities	Africa	https://www.dimensiondata.com/believe-in-greatness/connected-conservation
16.	**Connected mangroves project**	Sensors	Wetland Management	Malaysia	https://unfccc.int/climate-action/momentum-for-change/ict-solutions/connected-mangroves
17.	**COOL EARTH deforestation projects**	Satellite	Forest management	Cambodia, Peru, PNG, Mozambique, DRC	https://www.cornwalllive.com/news/business/how-tech-helping-cool-earth-2078606
18.	**Dayak drones**	Drones	Securing Land Rights	Indonesia	http://www.slate.com/articles/technology/future_tense/2015/06/community_drones_helps_indonesia_s_dayaks_protect_their_land.html
19.	**Digital Earth Africa**	Satellite	Grasslands	Africa	https://www.digitalearthafrica.org/
20.	**Drones fight pollution in Chinese Manufacturing Hub**	Drones	Air pollution prevention	China	http://www.xinhuanet.com/english/2017-09/05/c_136586310.htm
21.	**Drones to grow forests**	Drones	Forest management	Bangalore (India)	https://yourstory.com/2017/06/bengaluru-forest-drones
22.	**Drones to stop illegal fishing**	Drones	Marine species preservation	Mexico	http://www.takepart.com/article/2015/04/28/jamaica-drone-fish-save/
23.	**Drought Problem Quantification Project**	Satellite	Drought preparedness	Angola	https://www.plataformamedia.com/en-uk/news/society/drought-in-angola-will-be-monitored-by-satellite-11510815.html
24.	**e-eye**	Network Infrastructure	Terrestrial anti-poaching activities	India	https://wildtech.mongabay.com/2016/06/e-eye-tiger-complex-surveillance-system-extends-watch-indias-wildlife-sanctuaries/
25.	**E-logbooks Ecuador**	Push notification & Pull content	Sustainable fishing practices	Ecuador, Chile with potential expansion to Peru and more broadly across south America	https://www.worldwildlife.org/projects/smartphone-app-helps-communities-improve-their-fisheries-management

Programme name		Primary Tech	NRM Sector	Location	Link
26.	**EarthRanger**	Artificial Intelligence (AI)	Terrestrial species preservation	South Africa	https://earthranger.com/
27.	**Elephant texting - India**	Sensors	Human and wildlife interactions	India	http://www.earthisland.org/journal/index.php/articles/entry/early_warning_system_is_reducing_human-elephant_conflict_in_india/
28.	**Elephant texting - Kenya**	Sensors	Human and wildlife interactions	Kenya	https://www.seattletimes.com/nation-world/elephants-send-text-messages/
29.	**Empower**	Blockchain and distributed ledger	Preventing ocean pollution and promoting ocean clean-up	Developing countries	https://www.forbes.com/sites/trevorclawson/2018/12/19/the-blockchain-startup-that-plans-to-save-the-world-from-plastic-waste/#35db2ced6987
30.	**Fishcoin fisheries blockchain project**	Blockchain and distributed ledger	Sustainable fishing practices	Global	https://fishcoin.co/
31.	**Fishface**	Artificial Intelligence (AI)	Sustainable fishing practices	Indonesia	https://www.natureaustralia.org.au/what-we-do/our-priorities/provide-food-and-water-sustainably/food-and-water-stories/fishface/
32.	**Fishguard pilot**	Drones	Sustainable fishing practices	Seychelles	https://citizentruth.org/ai-drones-in-africa-track-illegal-fishing-poaching-and-deforestation/
33.	**Forest 2020 Project**	Satellite	Forest management	Kenya	https://news.mongabay.com/2018/11/radar-helps-kenya-map-mangroves-and-other-cloud-covered-forests/
34.	**Forest Link**	Push notification & Pull content	Forest management	Cameroon	https://cameroon.forestlink.org/home
35.	**Forest Watcher**	Push notification & Pull content	Forest management	Brazil	https://www.reuters.com/article/us-environment-forests-app/mobile-app-uses-real-time-satellite-data-to-strengthen-forest-and-land-rights-idUSKCN1C12FN
36.	**Forest-PLUS**	Niche devices	Forest management	India	https://www.tetratech.com/en/articles/tetra-tech-helps-promote-knowledge-transfer-remote-sensing-and-climate-change-mitigation
37.	**From Bait to Plate**	Blockchain and distributed ledger	Sustainable fishing practices	Fiji	https://wwf.panda.org/?226070/From-bait-to-plate
38.	**Galapagos drone**	Drones	Terrestrial invasive species and disease control	Galapagos	https://www.independent.co.uk/environment/drones-galapagos-island-rats-invasive-species-seabirds-conservation-a8746086.html
39.	**Ganja river plastics**	Drones	Preventing ocean pollution and promoting ocean clean-up	India, Bangladesh	https://india.mongabay.com/2019/08/how-does-plastic-pollute-the-ganga-an-all-women-scientists-expedition-is-looking-for-answers/
40.	**Georgia land registry system**	Blockchain and distributed ledger	Securing Land Rights	Georgia	https://www.forbes.com/sites/laurashin/2017/02/07/the-first-government-to-secure-land-titles-on-the-bitcoin-blockchain-expands-project/#ed018a94dcdc

Programme name		Primary Tech	NRM Sector	Location	Link
41.	**Ghana Land registry system - BenBen**	Blockchain and distributed ledger	Securing Land Rights	Ghana	http://www.benben.com.gh/
42.	**Global FinPrint**	Niche devices	Marine habitat protection and restoration	Global presence	https://globalfinprint.org/
43.	**Global Wildlife Whistleblower Program**	Push notification & Pull content	Wildlife Trafficking	Global	https://www.whistleblowers.org/wildlife/
44.	**Great elephant census**	Sensors	Terrestrial species preservation	Africa	http://www.greatelephantcensus.com/
45.	**Green Horizons**	Artificial Intelligence (AI)	Air pollution prevention	China	https://www.ibm.com/blogs/internet-of-things/air-pollution-green-initiatives/
46.	**Gunshot detection**	Sensors	Terrestrial species preservation	Northern Kenya	https://engineering.vanderbilt.edu/news/2017/engineering-tech-uses-elephant-poachers-own-weapons-against-them/
47.	**Harbin**	Artificial Intelligence (AI)	Terrestrial species preservation	China	http://www.chinadaily.com.cn/a/201907/31/WS5d40f33da310d83056401f23.html
48.	**Hejje**	Push notification & Pull content	Terrestrial species preservation	India	https://www.thehindu.com/news/national/karnataka/hejje-mobile-application-for-tracking-tigers-launched/article5649714.ece
49.	**Honduras Land registry system**	Blockchain and distributed ledger	Securing Land Rights	Honduras	https://siliconangle.com/2015/12/27/factoms-blockchain-land-reigstry-tool-trial-stalls-due-to-the-politics-of-honduras/
50.	**Imazon Mapping**	Inventory Management	Forest management	Brazil	https://imazon.org.br/en/?lang=en
51.	**India Ministry of Environment & Forests programs**	Satellite	Forest management	India	https://www.geospatialworld.net/article/technological-innovations-will-be-key-to-forest-resource-management-in-the-future/
52.	**Internet of Trees**	Sensors	Forest management	Honduras	http://internetoftrees.tech/
53.	**its4land**	Drones	Securing Land Rights	Kenya, Rwanda and Ethiopia	https://theconversation.com/drones-are-taking-to-the-skies-above-africa-to-map-land-ownership-87369
54.	**Jejak.in**	Artificial Intelligence (AI)	Forest management	Cameroon	https://cameroon.forestlink.org/home
55.	**Kruger National Park Project**	Drones	Terrestrial anti-poaching activities	South Africa	https://www.savetherhino.org/thorny-issues/the-use-of-drones-in-rhino-conservation/
56.	**Land Cover analysis for bamboo detection Ethiopia**	Satellite	Forest management	Ethiopia	https://openforests.com/project/land-cover-analysis-for-bamboo-detection-ethiopia/
57.	**Land registry systems - South America**	Blockchain and distributed ledger	Securing Land Rights	Bolivia, Peru and Uruguay	https://www.ledgerinsights.com/inter-american-development-bank-idb-blockchain-land-registry-chromway/

Programme name		Primary Tech	NRM Sector	Location	Link
58.	**LAWIN tool, Philippines**	Mobile handsets	Terrestrial species preservation	Philippines	https://dai-global-digital.com/designing-a-wildlife-identification-tool-in-philippines.html
59.	**Lion Activity in Meru National Park**	Satellite	Terrestrial species preservation	Kenya	https://www.bornfree.org.uk/articles/lion-activity-meru
60.	**Lukim Gather**	Push notification & Pull content	Terrestrial anti-poaching activities	Timor-Leste	https://postcourier.com.pg/mobile-application-a-new-tracking-tool-for-conservation/
61.	**MapMyRights (MMR) imitative**	Push notification & Pull content	Securing Land Rights	Global potential	http://rightsandresources.org/wp-content/uploads/RRI-Study-on-Costs-Final-Draft-ID-55782_Aug-20-FINAL.pdf
62.	**Marine debris tracker**	Push notification & Pull content	Preventing ocean pollution and promoting ocean clean-up	Global	http://marinedebris.engr.uga.edu/
63.	**mFish initiative**	Interactive content	Sustainable fishing practices	Indonesia	https://medium.com/fishcoin/a-brief-history-of-mfish-e89686d53fc2
64.	**Mitigating Floods and Fire Hazards in Forestry Using Internet of Things (IoT)**	Sensors	Forest management	Brunei	https://brudirect.com/news.php?id=78099
65.	**mKRISHI® Fisheries**	Push notification & Pull content	Sustainable fishing practices	India	https://www.icar.gov.in/node/4649
66.	**Mobile Application to Secure Tenure (MAST)**	Interactive content	Securing Land Rights	Tanzania, Burkina Faso, Zambia	https://landportal.org/blog-post/2018/04/how-technology-transforming-land-rights-tanzaniahttps:/land-links.org/tool-resource/mobile-applications-to-secure-tenure-mast/
67.	**MY AIR HEALTH**	Sensors	Monitoring and early warning system for air pollution	Global presence	http://www.paqs.biz/
68.	**Ocean cleanx**	Drones	Preventing ocean pollution and promoting ocean clean-up	Global	https://oceancleanx.com/ocean-cleanx-solution/
69.	**OceanMind (Microsoft AI for Earth)**	Artificial Intelligence (AI)	Sustainable fishing practices	Global	https://www.microsoft.com/en-us/ai/ai-for-earth-partners?activetab=pivot1:primaryr5
70.	**OLSPS Analytics - Electronic Monitoring**	Artificial Intelligence (AI)	Sustainable fishing practices	South Africa	https://www.all-turtles.com/2018/10/22/oceans-and-ai-the-quest-for-sustainable-fisheries/
71.	**Pelagic data systems**	Satellite	Sustainable fishing practices	Mexico	https://fronterasdesk.org/content/704823/satellite-monitoring-could-help-protect-rare-vaquita-marina-dolphin-mexicos-sea
72.	**Pench Tiger Reserve**	Drones	Marine anti-poaching activities	India	https://factordaily.com/drones-helping-forest-guards-track-poaching-pench/

Programme name		Primary Tech	NRM Sector	Location	Link
73.	**PIN early warning system - Vietnam**	Sensors	Building resilience to climate change	Cambodia	https://reliefweb.int/report/cambodia/cambodia-people-need-pin-places-climate-change-adaptation-high-our-agenda-pin-and
74.	**Plastic bank**	Blockchain and distributed ledger	Preventing ocean pollution and promoting ocean clean-up	Haiti, Indonesia, Philippines	www.plasticbank.com
75.	**Plastic for change**	Blockchain and distributed ledger	Preventing ocean pollution and promoting ocean clean-up	India	https://www.ibm.com/blogs/blockchain/2019/10/want-to-reduce-ocean-pollution-blockchain-is-paving-the-way/
76.	**POINTREK**	Satellite	Sustainable fishing practices	Indonesia	https://www.foodnavigator-asia.com/Article/2018/10/30/Satellites-for-sustainable-fishing-Indonesian-fishing-sector-to-benefit-from-international-project
77.	**Project Earth Observation**	Satellite	Terrestrial species preservation	Africa	https://www.janegoodall.org/uncategorized/earth-observation/
78.	**Project Leonardo**	Satellite	Human and wildlife interactions	Africa	https://www.panthera.org/initiative/project-leonardo
79.	**Protection Assistant for Wildlife Security (PAWS)**	Artificial Intelligence (AI)	Terrestrial anti-poaching activities	Global	https://www.microsoft.com/en-us/ai/ai-for-earth-partners?activetab=pivot1:primaryr8
80.	**Provenance blockchain project**	Blockchain and distributed ledger	Sustainable fishing practices	Indonesia	https://www.forbes.com/sites/keshiahannam/2016/09/30/this-emerging-tech-company-has-put-asias-tuna-on-the-blockchain/#7eebd78c2649
81.	**Rainforest Connection**	Sensors	Forest management	Global reach	https://www.ns-businesshub.com/science/rainforest-connection-phones-ai/
82.	**Rainforest Connection - Sumatra**	Sensors	Forest management	Indonesia	https://digitalsocial.eu/case-study/51/rainforest-connection-rfcx
83.	**RAPID**	Sensors	Terrestrial anti-poaching activities	Africa	https://www.hsi.org/news-media/protect-rapid-072015/
84.	**Rhino Protection in South Africa**	Sensors	Terrestrial species preservation	South Africa	https://www.globalnature.org/35085/Themes-Projects/Nature-Conservation/References/Rhino-Protection/resindex.aspx
85.	**São Paulo big data for air pollution**	Sensors	Monitoring and early warning system for air pollution	Brazil	https://aiforimpacttoolkit.gsma.com/resources/Big-Data-for-Social-Good_TEF_Brazil_Case-Study.pdf
86.	**São Paulo forest monitoring using drones**	Drones	Forest management	Sao Paulo, Brazil	https://www.scidev.net/global/forestry/news/drones-deployed-to-monitor-brazil-forest-growth.html

Programme name		Primary Tech	NRM Sector	Location	Link
87.	**Secure Tenure in African Cities: Micro Funds for Community Innovation**	Drones	Securing Land Rights	Democratic republic of the Congo	https://citiesalliance.org/how-we-work/our-programmes/innovation-programme/secure-tenure-african-cities/drones-land
88.	**Seneca Park Zoo tree tracking**	Satellite	Terrestrial habitat protection and restoration	Madagascar	https://news.mongabay.com/2019/11/tree-planting-programs-turn-to-tech-solutions-to-track-effectiveness/
89.	**SilviaTerra (Microsoft AI for Earth)**	Satellite	Forest management	Global	https://www.microsoft.com/en-us/ai/ai-for-earth-partners?activetab=pivot1:primaryr6
90.	**SkyEye**	Drones	Building resilience to climate change	Samoa	https://skyeyepacific.com/
91.	**Skylight**	Satellite	Marine anti-poaching activities	Palau, Gabon, Costa Rica	https://www.bloomberg.com/news/articles/2017-10-05/paul-allen-wants-to-use-satellites-and-software-to-fight-illegal-fishing
92.	**Smart Park**	Artificial Intelligence (AI)	Terrestrial anti-poaching activities	Africa	https://customers.microsoft.com/en-gb/story/peace-parks-foundation-ems-azure-nonprofit-south-africa-en
93.	**Smart Pole**	Network Infrastructure	Monitoring and early warning system for air pollution	India	https://www.nokia.com/about-us/news/releases/2018/10/26/bsnl-selects-nokia-for-smart-pole-deployment-across-india/
94.	**Smart water management sensing - Myanmar**	Sensors	Marine habitat protection and restoration	Myanmar	https://www.dutchwatersector.com/news/smart-sensoring-rolled-out-for-better-water-management-in-myanmar
95.	**Smart Water Meters in Niger**	Network Infrastructure	Water catchment management	Niger	https://www.veolia.com/africa/en/citytaps
96.	**SOI drone mapping**	Drones	Securing Land Rights	India	https://www.weforum.org/agenda/2019/10/india-using-drones-ai-digitally-map-country/
97.	**Spatial monitoring and reporting tool (SMART)**	Artificial Intelligence (AI)	Terrestrial anti-poaching activities	Africa, Asia, South America	https://www.livekindly.co/newton-blockchain-project-endangered-species/
98.	**SUM Africa**	Satellite	Drought preparedness	Mali and Uganda	https://g4aw.spaceoffice.nl/en/projects/g4aw-projects/62/scaling-up-micro-insurance-in-africa-sum-africa-.html
99.	**Survey Dugong/ seagrass**	Drones	Marine species preservation	Malaysia	http://www.dugongconservation.org/news/surveying-dugongs-seagrass-drones-lessons-learned-lawas-malaysia/
100.	**Swamp mapping in Subah**	Drones	Wetland Management	Borneo, (Indonesia)	https://www.rts.ch/info/monde/8038744.html

Programme name		Primary Tech	NRM Sector	Location	Link
101.	**Tahiti invasive species project**	Drones	Terrestrial invasive species and disease control	Tahiti	https://www.birdlife.org/worldwide/news/clones-vs-drones-tahiti-battles-nine-invasive-species-save-iconic-bird
102.	**Tech for Tigers**	Artificial Intelligence (AI)	Terrestrial species preservation	China	https://www.weforum.org/agenda/2018/08/here-s-how-technology-can-help-us-save-the-planet/
103.	**Thai Union - electronic trials**	Satellite	Sustainable fishing practices	Thailand	https://www.newsdeeply.com/oceans/community/2018/02/16/seafood-giant-tests-technology-to-prevent-illegal-fishing-worker-abuse
104.	**The Oceans and Fisheries Partnership, Asia-Pacific**	Sensors	Sustainable fishing practices	South East Asia	https://www.tetratech.com/en/projects/the-oceans-and-fisheries-partnership-usaid-oceans-asia-pacific
105.	**Thermal imaging lion conservation**	Niche devices	Terrestrial species preservation	Africa	https://www.instrumentation.co.uk/thermal-imaging-helps-lion-conservation-project/
106.	**Thermal Imaging Maasai Mara**	Niche devices	Terrestrial anti-poaching activities	Kenya	https://medium.com/@Carter_Roberts/applying-technology-to-our-conservation-mission-8101a4a0d9ec
107.	**Thuru: Trees growing project**	Peer-to-peer content	Forest management	Sri Lanka	https://thuru.lk/
108.	**Tigers forever**	Niche devices	Terrestrial anti-poaching activities	Bhutan, India, Indonesia, Malaysia, Nepal and Thailand	https://www.panthera.org/initiative/tigers-forever
109.	**Trash out**	Push notification & Pull content	Preventing ocean pollution and promoting ocean clean-up	Global reach	https://africanwastenetwork.org.za/news/mobile-apps-marine-debris/
110.	**Travel4Green**	Blockchain and distributed ledger	Forest management	Papua New Guinea	https://ipci.io/t4g/
111.	**Tree Tracking in Burkina Faso**	Satellite	Forest management	Burkina Faso	https://www.esri.com/about/newsroom/blog/tracking-tree-planting-sub-saharan-africa/
112.	**Treevia Smart Forest**	Sensors	Forest management	Global	https://treevia.com.br/2018/10/23/what-is-the-internet-of-things-anyways-how-does-it-affect-forestry/?lang=en
113.	**Using blockchain technology to protect rainforest**	Blockchain and distributed ledger	Forest management	Peru	https://rainforestfoundation.org/using-blockchain-technology-to-protect-the-rainforest/
114.	**Using drones to deter illegal fishing - Belize**	Drones	Marine species preservation	Belize	https://www.nationalgeographic.com/news/2016/12/drones-fight-pirate-fishing-belize-conservation/
115.	**Using drones to deter illegal fishing - Costa Rica**	Drones	Marine anti-poaching activities	Costa Rica	https://www.suasnews.com/2015/07/drones-could-help-spot-illegal-fishing-around-costa-ricas-cocos-island/
116.	**Using drones to deter illegal fishing - Jamaica**	Drones	Marine anti-poaching activities	Jamaica	http://www.takepart.com/article/2015/04/28/jamaica-drone-fish-save/

Programme name		Primary Tech	NRM Sector	Location	Link
117.	**Using drones to deter illegal fishing - Palau**	Drones	Marine anti-poaching activities	Palau	https://www.abc.net.au/news/2013-10-04/an-palau-drone-patrol-tests-to-deter-illegal-fishing-ends/4999344
118.	**Using technology to reduce sea turtle poaching**	Drones	Marine anti-poaching activities	Malaysia, Borneo, Philippines	https://www.fondationensemble.org/en/projet/developing-technology-to-combat-sea-turtle-poaching-in-southeast-asia-with-drones-uavs/
119.	**WEF and Intel project with Siberian tigers**	Artificial Intelligence (AI)	Terrestrial species preservation	China	https://medium.com/syncedreview/ai-in-wildlife-conservation-39f90782e959
120.	**Wild Me (Microsoft AI for Earth)**	Artificial Intelligence (AI)	Terrestrial species preservation	Global	https://www.microsoft.com/en-us/ai/ai-for-earth-partners?activetab=pivot1:primaryr7
121.	**Wild seve**	Call centres	Human and wildlife interactions	India	https://news.mongabay.com/2018/08/tech-goes-back-to-basics-to-mitigate-human-wildlife-conflict-near-indian-parks/
122.	**Wildleaks**	Push notification & Pull content	Terrestrial anti-poaching activities	Global	https://wildleaks.org/
123.	**Wildlife Alert**	Push notification & Pull content	Wildlife Trafficking	Afghanistan	https://www.viget.com/articles/wildlife-alert-an-app-to-combat-wildlife-trafficking/
124.	**Wildlife crime technology project**	Niche devices	Terrestrial anti-poaching activities	Africa	https://www.washingtonpost.com/gdpr-consent/?arc404=true&next_url=https%3a%2f%2fwww.washingtonpost.com%2fnews%2finnovations%2fwp%2f2015%2f06%2f03%2fhow-the-world-wildlife-fund-plans-to-fight-africas-poaching-problem%2f%3farc404%3dtrue
125.	**Wildlife Guardian**	Push notification & Pull content	Wildlife Trafficking	China	https://newsroom.wcs.org/News-Releases/articleType/ArticleView/articleId/8329/WCS-China-Wildlife-Guardian-App-Wins-Prestigious-Tech-Award.aspx
126.	**Wildlife insights**	Network Software	Terrestrial species preservation	Global	https://www.wildlifeinsights.org/team-network
127.	**Wildlife witness**	Push notification & Pull content	Wildlife Trafficking	South-East Asia	http://www.wildlifewitness.net/
128.	**WILDSCAN**	Interactive content	Wildlife Trafficking	Cambodia	https://www.wildlifealliance.org/tag/wildscan/
129.	**World Air Quality Index**	Push notification & Pull content	Monitoring and early warning system for air pollution	Global	https://www.iqair.com/world-air-quality-ranking
130.	**WWF Crime Technology Project**	Drones	Terrestrial anti-poaching activities	Namibia	https://www.dronezon.com/drones-for-good/wildlife-conservation-protection-using-anti-poaching-drones-technology/
131.	**WWF fisheries blockchain project**	Blockchain and distributed ledger	Sustainable fishing practices	Fiji	https://www.wwf.org.au/news/news/2018/how-blockchain-and-a-smartphone-can-stamp-out-illegal-fishing-and-slavery-in-the-tuna-industry#gs.l58vmf

Appendix D: Stakeholder list

The GSMA would like to acknowledge the contributions from the stakeholders interviewed and those that provided feedback during the course of this research. The organisations that took part in discussions about digital approaches to NRM are listed below:

- African Parks
- ATLAN Space
- Axiata
- Catalpa
- Cool Earth
- Department for International Development (DFID), UK
- Department of Foreign Affairs and Trade (DFAT), Australia
- E.co
- Ericsson
- Food and Agriculture Organization (FAO)
- gOtcha
- Green Africa Directory
- Huawei
- Mobitel
- PAQs
- Parley
- Rainforest Foundation UK
- Safaricom
- Sigfox
- SMART Philippines
- Southern African Wildlife College
- Telenor
- Thuru, Sri Lanka
- Vodacom (South Africa)
- Vulcan Inc
- World Wide Fund for Nature (WWF)

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