

# Enabling digital social innovations in environmental monitoring in support of Scotland's green recovery and the SDG 2030 agenda: a suggested strategy 2021-2025

SEFARI Fellowship report

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## Executive summary

We are facing a set of linked environmental challenges (climate change, biodiversity loss, and unsustainable natural resource use; often referred to as the planetary emergency or planetary crises). Monitoring the health of Scotland's rural, urban, and marine environments and our individual and collective impacts on them, is vital for enabling and guiding a green recovery and meeting the 2030 Sustainable Development Goals (SDG) agenda. The COVID-19 situation has impacted all areas of people's lives including how government agencies like NatureScot and SEPA are able to carry out environmental monitoring. The First Minister of Scotland and the President of the European Commission have set out common visions for twin green and digital transitions for Scotland and the European Union, respectively. Recently, David Jensen coordinator of the United Nations Environment Programme (UNEP) Digital Transformation Task Force, has set out a 10-year action agenda for harnessing data and digital transformation to accelerate environmental sustainability. These policies and plans depend on environmental monitoring data.

How we ensure continual improvement of environmental monitoring data pipelines through harnessing science and digital social innovations (people using data and digital technologies) to aid decision making to achieve global sustainability is at the heart of this report. Where an environmental monitoring data pipeline describes how data is collected e.g. by a sensor, is processed, stored, and then is made available for reuse. It is increasingly accepted that all environmental data should be findable, accessible, interoperable, and reusable (FAIR).

We set out a draft vision for digital social innovations in environmental monitoring to address local to global scale environmental challenges and support a green recovery. Building on existing initiatives e.g. Scotland's Environment Web (SEWeb) and linking with UNEP's. This requires harnessing shared understanding and common purpose across Scotland's monitoring communities to enable people to work together, often with the help of technology, to mobilise a wider range of information, ideas, and insights to address local to global scale environmental challenges.

**Our draft vision is for data-information-knowledge, based on environmental monitoring data flows, to be findable and accessible to whoever needs it, interoperable with existing and new applications and workflows/data pipelines, and that it is widely reused from individual to national level decision making to improve the climate change, biodiversity loss, and unsustainable use of natural resources challenge situations as part of a green technology-led recovery.** We suggest our draft vision could be delivered through four linked missions (and recommended actions), one cross-cutting integrative mission and three missions targeted on improving climate change, biodiversity loss, and unsustainable use of natural resources challenge situations.

Suggested mission 1: Bring together researchers, innovation centres, Centres of Expertise, Scottish Government and its agencies, and business stakeholders in a community of practice by 2021 to build Scotland's capacity in environmental monitoring data flows and digital environments to enhance our collective intelligence and encourage digital social innovation by the end of 2025.

Suggested mission 2: Improve environmental monitoring data flows in relation to Scotland's **changing climate** from emissions, mitigation to adaptation, so these are findable and accessible to whoever needs them, interoperable with existing and new applications and workflows/data pipelines, and that it is widely reused from individual to national level decision making by 2025.

Suggested mission 3: Improve environmental monitoring data flows in relation to Scotland's **biodiversity** so these are findable and accessible to whoever needs them, interoperable with existing and new applications and workflows/data pipelines, and that it is widely reused from individual to national level decision making by 2025.

Suggested mission 4: Improve environmental monitoring data flows in relation to Scotland's **unsustainable use of natural resources**, so these are findable and accessible to whoever needs them, interoperable with existing and new applications and workflows/data pipelines, and that it is widely reused from individual to national level decision making by 2025.

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## 1. Local to global environmental challenges and policy responses

We are facing a set of linked environmental challenges (climate change, biodiversity loss, and unsustainable natural resource use; often referred to as the planetary emergency<sup>1</sup> or planetary crises) that are due to how we as individuals, organisations, businesses, and nations interact with our planet's environment (Box 1). Monitoring the health of Scotland's rural, urban, and marine environments and our individual and collective impacts on them, is vital for enabling and guiding a green recovery and meeting the 2030 Sustainable Development Goals (SDG) agenda, as highlighted by the recently published 8<sup>th</sup> European Environment Action Programme<sup>2</sup>. At the 2020 United Nations Internet Governance Forum session 'Environmental issues in the era of digital transformation', David Jensen (UNEP coordinator of the Digital Transformation Task Force) said<sup>3</sup>: "to solve the planetary crises in the next ten years we need to embed environmental data and sustainability metrics into the digital economy to inform and transform decision making across all sectors".

Box 1. The European environment — state and outlook 2020: knowledge for transition to a sustainable Europe.

"In 2020, Europe faces environmental challenges of unprecedented scale and urgency. Although EU environment and climate policies have delivered substantial benefits over recent decades, Europe faces persistent problems in areas such as biodiversity loss, resource use, climate change impacts, and environmental risks to health and well-being." (SOER 2020, 9).

"The next 10 years. Achieving the goals of the 2030 agenda for sustainable development and the Paris Agreement will require urgent action...sustainability needs to become the guiding principle for ambitious and coherent policies and actions across society. Enabling transformative change will require that all areas and levels of government work together and harness the ambition, creativity and power of citizens, businesses, and communities. In 2020, Europe has a unique window of opportunity to lead the global response to sustainability challenges. Now is the time to act." (SOER 2020, 17).

Environmental monitoring is the foundation of how we understand our impacts on our rural, urban, and marine environments and is key to "advancing methodologies that integrate the complexity of human–environmental systems into analyses that underlie effective solutions" (Galvani et al. 2016). How we ensure continual improvement of environmental monitoring data pipelines through harnessing science and digital social innovations (people using data and digital technologies) to aid decision making to achieve global sustainability is at the heart of this report. Where an environmental monitoring data pipeline describes how data is collected e.g. by a sensor, is processed and stored, and then is made available for reuse. It is increasingly accepted that all environmental data should be findable, accessible, interoperable, and reusable (FAIR) (Wilkinson et al. 2016). Though there has been some progress in meeting some of these principles, large amounts of environmental monitoring data do not meet the FAIR principles.

In this section, we expand on these environmental challenges and recent Scottish, UK, European, and global policy responses that are increasingly framed as twin digital and green transitions to a more resilient, green, and digital Scotland and Europe. In Section 2, we present the key roles of environmental monitoring to support these policy responses. Then in Section 3, we provide a draft vision and suggest four linked missions (and recommended actions) for **how digital social**

<sup>1</sup> [https://www.leaderspledgefornature.org/Leaders\\_Pledge\\_for\\_Nature\\_27.09.20.pdf](https://www.leaderspledgefornature.org/Leaders_Pledge_for_Nature_27.09.20.pdf) (accessed 191120)

<sup>2</sup> [https://ec.europa.eu/environment/strategy/environment-action-programme-2030\\_en](https://ec.europa.eu/environment/strategy/environment-action-programme-2030_en) (accessed 191120)

<sup>3</sup> [https://youtu.be/rcUBL\\_6zV9w?t=3751](https://youtu.be/rcUBL_6zV9w?t=3751) (accessed 191120)

**innovations in environmental monitoring can address environmental challenges and support a green recovery.** Digital social innovation (also known as civic tech) is about using data and technology to mobilise people to solve some of society's biggest challenges. It is clear at the local to global scales that our rural, urban, and marine environments face tremendous challenges (illustrated in Box 1) due to our activities. This report is an output from a SEFARI<sup>4</sup> – Scottish Environment, Food and Agriculture Research Institutes Fellowship.

## 1.1 Linked environmental challenges

Environmental monitoring is vital for understanding and addressing the linked environmental challenges of climate change, biodiversity loss, and unsustainable use of natural resources. In this section, we provide a brief overview of these connected environmental challenges.

### 1.1.1 Climate change

A 2020 update on the scientific assessments of the Intergovernmental Panel on Climate Change (IPCC) by Forster and Le Quéré stated that previous IPCC assessments were accurate in terms of the impacts of climate change<sup>5</sup>, with the first IPCC report (1990) predicting the observed rate of global warming very well<sup>6</sup>. This was possible due to learning more about how the world works from careful monitoring, analysis, and improvements in climate models. With confidence we can say warming is unfolding as projected; based on the 2013 IPCC assessment report<sup>7</sup>, global temperature has continued to rise. For example, flooding in Scotland and the UK is expected to get worse unless we adapt, with winter-time extremes of UK rainfall increasing by 7% or more per degree of global warming<sup>8</sup>. The UK Climate Change Risk Assessment 2017 Evidence Report: summary for Scotland<sup>9</sup> highlighted how climate change was increasing flood risks to natural environment and natural assets, infrastructure, people and the built environment, and business and industry. As well as predicted increases in drought risk and low river flows impacting natural and build environments. The recent Adaptation Scotland 2021 climate predictions suggests that by 2080 Scottish winters will be 5 to 19% wetter and 1.1 to 2.7 °C warmer, under low and high global emission scenarios respectively<sup>10</sup>.

### 1.1.2 Biodiversity loss

The first global assessment of biodiversity and ecosystem services, in 2019, revealed that nature around the globe has been significantly altered by human activity and an average of 25 percent of species in assessed plant and animal groups being threatened with extinction<sup>11</sup>. The State of Nature Scotland report 2019 report<sup>12</sup> showed that from 1994 to 2016, 49% of Scottish species have decreased and 28% had increased in abundance. In addition to summaries of trends in abundance and occupancy, it explored how key pressures were acting on Scotland's nature, these included: agricultural management, climate change, hydrological change, urbanisation, woodland management, pollution, invasive non-native species, upland management, marine climate change and fisheries. The State of Nature Report Scotland<sup>13</sup> highlighted that all our wildlife is undergoing rapid change. With average species' abundance of 352 terrestrial and freshwater species falling by 24% since 1994, and average species' distribution (covering 2,970 terrestrial and freshwater species)

<sup>4</sup> <https://sefari.scot/> (accessed 101220)

<sup>5</sup> <https://www.theccc.org.uk/2020/05/04/climate-change-is-getting-worse-but-it-is-no-worse-than-we-predicted/> (accessed 281020)

<sup>6</sup> <https://www.carbonbrief.org/analysis-how-well-have-climate-models-projected-global-warming> (accessed 281020)

<sup>7</sup> <https://www.ipcc.ch/report/ar5/wg1/> (accessed 281020)

<sup>8</sup> <http://www.climatechange2013.org/report/reports-graphic/ch7-graphics/> (accessed 281020)

<sup>9</sup> <https://www.theccc.org.uk/wp-content/uploads/2016/07/UK-CCRA-2017-Scotland-National-Summary.pdf> (accessed 101220)

<sup>10</sup> <https://www.adaptationscotland.org.uk/news-events/stories/new-climate-projections-summary-scotland> (accessed 090221)

<sup>11</sup> <https://ipbes.net/global-assessment> (accessed 290920)

<sup>12</sup> <https://www.nature.scot/state-nature-scotland-report-2019> (accessed 021020)

<sup>13</sup> <https://www.nature.scot/sites/default/files/2019-10/State-of-nature-Report-2019-Scotland-full-report.pdf> (accessed 021020)

having fallen by 14% since 1970, including a 38% decline in the Scottish breeding seabird indicator between 1986 and 2016. A 2018 report<sup>14</sup> ‘Scotland’s Nature on Red Alert: Climate change impacts on biodiversity’ highlighted negative impacts on Scotland’s habitats including rising monthly average temperatures of rivers, increased temperatures of coastal waters, and decreases in days of snow cover in mountain habitats.

### 1.1.3 Unsustainable natural resource use

Europe’s environmental footprint is exceeding several safe limits. A joint study<sup>15</sup> by the European Environment Agency (EEA) and the Swiss Federal Office for the Environment (FOEN) explored ways of defining Europe’s share of the global safe operating space; it showed that Europe is not yet living within those limits. They used a consumption-based analysis for four of the Earth’s life support systems, with Europe exceeding its safe operating space for nitrogen cycle by a factor of 3.3, phosphorous cycle by a factor of 2.0, and land system change by a factor of 1.8.

## 1.2 Policy responses

### 1.2.1 To environmental challenges

In February 2020, the Scottish Government launched its Environment Strategy<sup>16</sup>. In this it set out a vision that “by 2045: By restoring nature and ending Scotland’s contribution to climate change, our country is transformed for the better”. The strategy provides a high-level framework for Scotland’s existing environmental strategies and plans. It is explicit about the central role of evidence in its development and application, saying “the quality of evidence on our environment in Scotland, and on the effectiveness of policies, is mixed”. The strategy makes it clear that they “will develop a monitoring framework to track progress in delivering our Environment Strategy – helping to inform improvements in our approach”. The recent Scottish Government 2020 Biodiversity Post-2020: A Statement of Intent, said it would “...devise a programme of monitoring, assessment and reporting to support implementation of the new biodiversity strategy” (P21)<sup>17</sup>.

The Scottish Budget in 2020-21<sup>18</sup> set out how the Scottish Government was responding to the global climate emergency, through accelerating Scotland’s transition to a net-zero economy. In 2019, the Scottish Parliament passed the Climate Change (Emissions Reduction Targets) (Scotland) Act that set a target date for net-zero emissions of all greenhouse gases by 2045. A recent progress report<sup>19</sup> on Scotland’s greenhouse gas emissions (ninth annual Progress Report to the Scottish Parliament, as required by the Climate Change (Scotland) Act 2009), showed that though emissions fell by 31% from 2008 to 2018 (primarily due to emission reductions in the power sector), recent emissions increased by 2% in 2018, compared to a reduction of 3% in 2017.

SEPA’s CEO, Terry A’Hearn, has been implementing his vision - One Planet Prosperity, which is about addressing 21<sup>st</sup> Century environmental challenges by SEPA enabling individuals and organisations to go beyond compliance. SEPA have developed a series of sector plans to influence and work in partnership to improve sustainability. SEPA in their Annual Operating Plan 2020-2021<sup>20</sup>, preparing for a different world that emerges after COVID-19, stated that: “We must also be bold to create a

<sup>14</sup> [https://www.wwf.org.uk/sites/default/files/2018-12/WWF\\_Link\\_Scotlands\\_Nature\\_on\\_Red\\_Alert\\_%20%28003%29\\_0.pdf](https://www.wwf.org.uk/sites/default/files/2018-12/WWF_Link_Scotlands_Nature_on_Red_Alert_%20%28003%29_0.pdf) (accessed 101220)

<sup>15</sup> <https://www.eea.europa.eu/highlights/europes-environmental-footprints-exceed-several> (accessed 281020)

<sup>16</sup> <https://www.gov.scot/publications/environment-strategy-scotland-vision-outcomes/> (accessed 021020).

<sup>17</sup> <https://www.gov.scot/binaries/content/documents/govscot/publications/strategy-plan/2020/12/scottish-biodiversity-strategy-post-2020-statement-intent2/documents/scottish-biodiversity-strategy-post-2020-statement-intent/scottish-biodiversity-strategy-post-2020-statement-intent/govscot%3Adocument/scottish-biodiversity-strategy-post-2020-statement-intent.pdf> (accessed 090221)

<sup>18</sup> <https://www.gov.scot/publications/scottish-budget-2020-21/> (accessed 281020)

<sup>19</sup> <https://www.theccc.org.uk/publication/reducing-emissions-in-scotland-2020-progress-report-to-parliament/> (accessed 281020)

<sup>20</sup> [https://www.sepa.org.uk/media/504023/sepa-aop-2020-2021-vfinal\\_renumbered.pdf](https://www.sepa.org.uk/media/504023/sepa-aop-2020-2021-vfinal_renumbered.pdf) (accessed 281020)

better way of living that provides prosperity for all within the means of one planet”. NatureScot in their Corporate plan for 2018-2020<sup>21</sup> set out how they will work in “collaboration, and viewing nature as part of wider social and economic challenges and opportunities is central to our approach - for example, in tackling climate change and nature together”.

The UK Government announced ‘A Green Future: Our 25 Year Plan’ to improve the environment in 2018<sup>22</sup>, this was followed in 2019 by a framework of 66 indicators across 10 broad themes<sup>23</sup>; with a central role for monitoring and evaluation of what has been achieved and have interventions worked. The importance of place/location has long been recognised. And earlier in 2020 the UK Government launched a Geospatial Strategy<sup>24</sup> that sets out a coordinated approach to unlock economic, social, and environmental value from geospatial data. With a vision that by 2025 the UK will have a coherent national location data framework.

At the EU level, Ursula von der Leyen, President of the European Commission, took office in December 2019 and presented the European Green Deal – a roadmap for making the EU’s economy sustainable by turning environmental challenges into opportunities across all areas of policy<sup>25</sup>. A series of plans e.g. Circular Economy Action Plan<sup>26</sup> followed building on earlier assessments, for example the European Environment Agency’s (EEA) 2019 report<sup>27</sup> on how to measure the condition of Europe’s natural capital; this contained the first assessment of the state and trends of Europe’s ecosystems. The authors highlighted the need for better data on the condition of ecosystems in Europe; this would require more targeted monitoring of biodiversity integrated with satellite observations and other statistical data.

In 2019, UNEP were tasked with establishing a global environmental data strategy<sup>28</sup> to combat the fragmentation of data and applications and enable access to environmental sustainability data for regulators, investors, producers, and consumers. Earlier in 2020, a global agenda for a digital ecosystem for Earth was proposed<sup>29</sup> by David Jensen and colleagues. During 2020, the German Environment Agency (Umweltbundesamt-UBA) together with United Nations Development Programme, UNEP, Future Earth and International Science Council started an initiative called ‘A Digital Planet for Sustainability’<sup>30</sup>, which brings together science community, governmental institutions, UN organisations e.g. UNEP, technology companies, and civil society. Because digitalization creates new opportunities for implementing the 2030 agenda and the UN's sustainability goals including environmental and climate protection.

### 1.2.2 In support of a green and digital recovery following COVID-19

The COVID-19 situation has impacted all areas of people’s lives including how government agencies like NatureScot and SEPA are able to carry out environmental monitoring. Recent Scottish and European policy responses are increasingly framed as twin digital and green transitions to a more resilient, green, and digital Scotland and Europe. The Scottish Government’s Programme for

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<sup>21</sup> <https://www.nature.scot/connecting-people-and-nature-corporate-plan-2018-2022> (accessed 191120)

<sup>22</sup> <https://www.gov.uk/government/publications/25-year-environment-plan> (accessed 281020)

<sup>23</sup> [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/802094/25-yep-indicators-2019.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/802094/25-yep-indicators-2019.pdf) (accessed 281020)

<sup>24</sup> <https://www.gov.uk/government/publications/unlocking-the-power-of-locationthe-uks-geospatial-strategy> (accessed 281020)

<sup>25</sup> [https://ec.europa.eu/commission/presscorner/detail/e%20n/jp\\_19\\_6691](https://ec.europa.eu/commission/presscorner/detail/e%20n/jp_19_6691) (accessed 271020)

<sup>26</sup> <https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN> (accessed 191120)

<sup>27</sup> <https://www.eea.europa.eu/highlights/measuring-condition-of-europes-ecosystems> (accessed 281020).

<sup>28</sup> [https://wedocs.unep.org/bitstream/handle/20.500.11822/29753/Item%204%20UNEP\\_UNEA4\\_Monitoring\\_Ministerial\\_Declaration\\_Thu-12-Sep-2019.pdf?sequence=1&isAllowed=y](https://wedocs.unep.org/bitstream/handle/20.500.11822/29753/Item%204%20UNEP_UNEA4_Monitoring_Ministerial_Declaration_Thu-12-Sep-2019.pdf?sequence=1&isAllowed=y) (accessed 191120)

<sup>29</sup> [https://medium.com/@davidedjensen\\_99356/digital-planet-20-priorities-3778bf1dbc27](https://medium.com/@davidedjensen_99356/digital-planet-20-priorities-3778bf1dbc27) (accessed 191120)

<sup>30</sup> <https://www.umweltbundesamt.de/en/topics/sustainability-strategies-international/global-initiative-on-a-digital-planet-for> (accessed 191120)

Scotland 2020-2021<sup>31</sup> set out a national mission to help create new jobs, good jobs, and green jobs. With an emphasis on technology to underpin a green recovery.

The COVID-19 situation has increased data sharing and collaboration across a wide range of Scottish organisations, for example monitoring of wastewater samples for coronavirus ribonucleic acid<sup>32</sup>. At the recent Digital Scotland 2020 event<sup>33</sup> session on 'A data and AI vision for Scotland' Albert King (Chief Data Officer, Scottish Government), and others, said that the COVID-19 situation had increased capacity and expectations for how public and private data is handled in Scotland, highlighting the value of data to aid decision making.

In Scotland, the government's consultation (to December 2020) 'Renewing Scotland's full potential in a digital world'<sup>34</sup> stated that "Scotland is recognised throughout the world as a vibrant, inclusive, greener, open and outward-looking digital nation" is more compelling due to the COVID-19 pandemic. It highlighted the need to understand and respond by building a Digital Scotland which ensures "green thinking is incorporated into all our digital solutions, so we can contribute to meet our statutory commitments to be a net zero society by 2045; and we are open, ethical and working with others to meet new moral, environmental, regulatory and security concerns." And that the "pandemic has underlined the importance of digital capacity and capability in ensuring a robust, inclusive, wellbeing economy with the resilience to deal with such cataclysmic disruptions".

At the UK level, the Joint Nature Conservation Committee (JNCC) plays key roles in a range of UK environmental monitoring networks "by co-ordinating nature conservation action at a UK level; working in partnerships to provide common approaches, shared solutions and best practice; and providing a cost-effective and robust environmental evidence base across the UK"<sup>35</sup>. A 2020 blog post sets out their role to support policy and operational decisions for a green recovery through the provision of robust evidence and advice based on environmental monitoring<sup>36</sup>.

Even before widespread local to national scale lockdowns to deal with COVID-19 there was a clear pattern of rapid technological change leading to 'digital disruption' (McQuivey, 2013): of how we live, do business, and the opportunities and challenges for sustainable development<sup>37</sup>, and the increasing importance of digital social innovation to tackle societal challenges. During the first half of 2019, reports of increased rates of digital transformation started appearing<sup>38</sup>. Over the summer the recommendations to the Scottish Government from the Advisory Group on Economic Recovery highlighted the importance of a technology-led green recovery<sup>39</sup>.

In her State of the Union address President von der Leyen said<sup>40</sup> "A world where we use digital technologies to build a healthier, greener society...We are reaching the limits of the things we can do in an analogue way. And this great acceleration is just beginning...We need a common plan for digital Europe with clearly defined goals for 2030, such as for connectivity, skills and digital public services...But Europe must now lead the way on digital – or it will have to follow the way of others, who are setting these standards for us. This is why we must move fast."

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<sup>31</sup> <https://www.gov.scot/publications/protecting-scotland-renewing-scotland-governments-programme-scotland-2020-2021/> (accessed 101220)

<sup>32</sup> <https://informatics.sepa.org.uk/RNAmonitoring/> (accessed 101220)

<sup>33</sup> <https://canongate.swoogo.com/digitalscotlandvirtual> (accessed 101220)

<sup>34</sup> <https://www.gov.scot/publications/renewing-scotlands-full-potential-digital-world/> (accessed 161120)

<sup>35</sup> <https://jncc.gov.uk/our-role/the-uk/> (accessed 221120)

<sup>36</sup> <https://jncc.gov.uk/about-jncc/jncc-blog/archive/jnccs-role-in-the-green-recovery/> (accessed 221120)

<sup>37</sup> <https://unctad.org/en/pages/PublicationWebflyer.aspx?publicationid=2674> (accessed 290920)

<sup>38</sup> <https://www.microsoft.com/en-us/microsoft-365/blog/2020/04/30/2-years-digital-transformation-2-months/> (accessed 290920)

<sup>39</sup> <https://www.gov.scot/news/working-towards-economic-recovery/> (accessed 281020)

<sup>40</sup> [https://ec.europa.eu/commission/presscorner/detail/en/SPEECH\\_20\\_1655](https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_20_1655) (accessed 290920)



The UN Secretary General at the 2020 UN Biodiversity Summit set out three priorities for conserving and sustainably managing biodiversity<sup>41</sup>: “First, nature-based solutions must be embedded in COVID-19 recovery and wider development plans. Second, our economic systems and financial markets must account for and invest in nature. Third, we must secure the most ambitious policies and targets that protect biodiversity and leave no one behind”. In response international Leader’s Pledge for Nature<sup>42</sup> reinforced the urgent need to address the drivers of the planetary emergency (connected crises of biodiversity loss, ecosystem degradation, and climate change) during the current UN Decade of Action<sup>43</sup> to achieve sustainable development.

## 2. Monitoring environmental challenges and support a green recovery

### 2.1 Environmental monitoring: data pipelines and human-environment systems

It is often said, that ‘if you cannot monitor it, you cannot manage it’. This is why companies e.g. Planet<sup>44</sup>, individual countries e.g. USA’s Landsat program<sup>45</sup>, and groups of countries e.g. European Space Agency<sup>46</sup> continue to invest heavily in earth observation satellite missions and cloud based platforms to help make the data findable, accessible, interoperable, and that it is reused to address environmental challenges. In Scotland, there are a wide range of short- and longer-term, local to national scale, environmental monitoring initiatives that take place to support a range of public policy and business objectives (see Section 2.1.2 for examples).

Where “environmental monitoring describes the processes and activities that need to take place to characterize and monitor the quality of the environment.”<sup>47</sup> It involves diverse data pipelines, workflows and social processes related to the data and technology ecosystem (Table 1). Data ecosystems is a term used to describe systems made up of people, practices, values, and technologies designed to support specific communities of practice. A data pipeline can be described as a set of processes that take raw data e.g. collected by *in-situ* or remote sensors, and which is transformed in a way that is usable by a range of people and organisations (often called ‘end users’); these processes involve a series of quality assurance and quality controls steps, and may have differing levels of automation e.g. new JNCC/Scottish Government’s Sentinel satellite ‘Simple ARD (analysis ready data) Service’<sup>48</sup> has greater levels of automation than national schemes of volunteer based biological monitoring of species.

Simply, improving the collection of data is not enough. Creating value from data requires individuals and organisations to have access to data and use it effectively and appropriately for specific purposes. The UK Royal Academy of Engineering have provided guidance<sup>49</sup> on improving trusted data sharing as a key step in the data value chain, which spans data generation, data sharing, data analysis, decision making, and outcomes. A classic paper by Lovett et al. (2007) ‘Who needs environmental monitoring?’ suggested that effective monitoring programmes needed high data quality, accessibility, and cost-effectiveness, and that government agencies and other funding

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<sup>41</sup> <https://www.un.org/sg/en/content/sg/statement/2020-09-30/secretary-generals-remarks-united-nations-biodiversity-summit-delivered> (accessed 261020)

<sup>42</sup> <https://www.leaderspledgefornature.org/> (accessed 290920)

<sup>43</sup> <https://www.un.org/sustainabledevelopment/decade-of-action/> (accessed 290920)

<sup>44</sup> <https://www.planet.com/> (accessed 221120)

<sup>45</sup> <https://landsat.gsfc.nasa.gov/> (accessed 221120)

<sup>46</sup> <https://www.esa.int/> (accessed 221120)

<sup>47</sup> [https://en.wikipedia.org/wiki/Environmental\\_monitoring](https://en.wikipedia.org/wiki/Environmental_monitoring) (accessed 300920)

<sup>48</sup> <https://jncc.gov.uk/our-work/simple-ard-service/> (accessed 281020)

<sup>49</sup> <http://reports.raeng.org.uk/datasharing/cover/> (accessed 281020)

institutions should commit to increasing the amount and long-term stability of funding for environmental monitoring programmes; these requirements have not changed.

Table 1. Components of digital environments, why needed, and recent innovations.

Components	Why are they needed?	Recent innovations
Data and infrastructure architecture	Digital environments are composed of multiple components, which can be connected in a range of patterns.	Databricks <sup>50</sup> is a data analytics platform <sup>51</sup> . A range of data pipe innovations from classic Apache Airflow <sup>52</sup> to recent examples like Monte Carlo <sup>53</sup> .
Geospatial dashboards (2, 3 and 4D)	Interactive visual interfaces (web and mobile) provide people with the ability to explore data based on their needs.	Applications that harness WebGL <sup>54</sup> and Graphics Processing Units (GPUs) <sup>55</sup> e.g. CesiumJS <sup>56</sup> (JavaScript library for creating 3D globes and maps) and deck.gl <sup>57</sup> visualisation framework for large datasets.
Satellite and drone remote sensing data	Satellite (and drone) remote sensing data, along with ground truthing data, are used to observe species and habitats e.g. a woodland.	Free medium resolution e.g. ESA Sentinel <sup>58</sup> data, higher resolution commercial data (e.g. Planet <sup>59</sup> ), 'analysis ready data' through data cubes (e.g. Open Data Cube <sup>60</sup> ), and low-cost drones.
<i>In-situ</i> sensor data	To understand the state of soil (e.g. water content) or water bodies (e.g. changes in levels).	Advances in low cost sensor hardware network protocols e.g. LoRaWAN <sup>61</sup> and NB-IoT <sup>62</sup> , and on device machine learning e.g. TinyML <sup>63</sup> .
Databases	Once data has been collected, it needs to be stored to enable processing and reuse.	Due to an increase in Internet of Things (IoT) sensors, then there have been rapid innovations in time series databases <sup>64</sup> .
Cloud-based micro-services <sup>65</sup>	Many enterprise systems have moved from monolithic to micro-services. Environmental models (explicit knowledge) need to benefit from these innovations.	There has been increased uses of 'serverless' (Functions as a Service) <sup>66</sup> to enable people to focus on their business logic. Technologies like Docker <sup>67</sup> containers and orchestration tools e.g. Kubernetes <sup>68</sup> enable cloud-based micro-services.
Machine (including deep) learning	Machine learning is vital for extracting information and knowledge from sensor time series data from sensors (e.g. IoT) and satellite imagery.	The widespread use of deep learning (multiple layers of artificial neural networks) has been enabled though Python libraries like TensorFlow <sup>69</sup> and PyTorch <sup>70</sup> access to GPUs, and ability to transfer a trained model from one context to another <sup>71</sup> .

<sup>50</sup> <https://databricks.com/> (accessed 201120)

<sup>51</sup> <https://databricks.com/product/unified-data-analytics-platform> (accessed 201120)

<sup>52</sup> <https://airflow.apache.org/> (accessed 201120)

<sup>53</sup> <https://www.montecarlodata.com/product/> (accessed 201120)

<sup>54</sup> <https://www.khronos.org/webgl/> (accessed 201120)

<sup>55</sup> [https://en.wikipedia.org/wiki/Graphics\\_processing\\_unit](https://en.wikipedia.org/wiki/Graphics_processing_unit) (accessed 201120)

<sup>56</sup> <https://cesium.com/cesiumjs/> (accessed 201120)

<sup>57</sup> <https://deck.gl/> (accessed 201120)

<sup>58</sup> <https://sentinel.esa.int/web/sentinel/home> (accessed 201120)

<sup>59</sup> <https://www.planet.com/> (accessed 201120)

<sup>60</sup> <https://www.opendatacube.org/> (accessed 201120)

<sup>61</sup> <https://lora-alliance.org/> (accessed 201120)

<sup>62</sup> <https://www.gsma.com/iot/narrow-band-internet-of-things-nb-iot/> (accessed 201120)

<sup>63</sup> <https://www.tinyml.org/home/index.html> (accessed 201120)

<sup>64</sup> <https://db-engines.com/en/ranking/time+series+dbms> (accessed 201120)

<sup>65</sup> <https://martinfowler.com/articles/microservices.html> (accessed 201120)

<sup>66</sup> [https://en.wikipedia.org/wiki/Serverless\\_computing](https://en.wikipedia.org/wiki/Serverless_computing) (accessed 201120)

<sup>67</sup> <https://www.docker.com/> (accessed 201120)

<sup>68</sup> <https://kubernetes.io/> (accessed 201120)

<sup>69</sup> <https://www.tensorflow.org/> (accessed 201120)

<sup>70</sup> <https://pytorch.org/> (accessed 201120)

<sup>71</sup> <https://machinelearningmastery.com/transfer-learning-for-deep-learning/> (accessed 201120)

Knowledge graphs <sup>72</sup> and semantic technologies	Understand links between real-world entities and knowledge associated with them (e.g. status of a specific water body).	Organisations e.g. Microsoft <sup>73</sup> and Earth Science Information Partnership <sup>74</sup> are using JSON-LD <sup>75</sup> to represent knowledge. Google's Dataset search <sup>76</sup> is increasing in use.
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Traditionally, environmental monitoring has focussed on biophysical data like river flows and presence of biological species; what is increasingly realised is the need for socio-economic data alongside these to enable monitoring and evaluation of environmental policies (Waylen et al., 2019). A survey of European Long-term Socio-Ecological Research sites found they mainly focussed on ecosystem/biophysical (72%) research compared to social system research (28%) (Angelstam 2019).

A recent report by the European Environment Agency (EEA) on the desire at the European (and Scottish) level to move to a circular economy highlighted the need for robust monitoring and targets<sup>77</sup>. Their survey found a general lack of target setting across Europe (these are needed to improve resource efficiency and drive the circular economy). They identified that a universally accepted set of indicators would improve the setting of targets and contribute to a comprehensive monitoring system.

In a Scottish context there is monitoring at a range of levels, for example national level policy monitoring and reporting on the state of natural capital, to local level monitoring on the state of a particular protected habitat (Natura 2000) or water body (EU WFD 2000/60/EC) for wildlife or flooding risks. Initiatives like the recently announced SEPA and Scottish Wildlife Trust £1 billion for nature conservation will require monitoring<sup>78</sup>. The route map includes approaches which aim to stimulate investment in Scotland's natural capital by delivering a financial return to investors.

Policy making and management decisions from the local to global level are dependent on shared environmental information systems. Aggestam (2019) described his experiences of the EU Shared Environmental Information System (SEIS): need better understanding of environmental data types, data packaging and data flows across multiples contexts, epistemic cultures and policy making. Community-based monitoring or citizen observatories are a type of SEIS, where citizens have a greater role in planning and collecting data and its analysis. A review by Wehn (2019) found their success was dependent on active participation and commitment of all stakeholders (including decision and policy makers as well as professional scientists), and understanding their motivations, incentives, and barriers for participating.

### 2.1.1 Data pipelines, digital environments, and communities of practice

Digital automation of data pipelines and their central role in the creation, use, and testing of digital environments are at the core of environmental monitoring in 2021 and how it can support a green and technology-led recovery. With early work on digital environments (also referred to as digital earths or digital environmental twins) stemming from Al Gore's (1992) book 'Earth in Balance'. In 2011, the International Society for Digital Earth stated the next generation of Digital Earths will not be a single system, but, rather, multiple connected infrastructures based on open access and participation across multiple technological platforms that will address the needs of different audiences (Craglia et al., 2012). More recently, the engineering community has embraced the

<sup>72</sup> <https://towardsdatascience.com/knowledge-graph-bb78055a7884> (accessed 201120)

<sup>73</sup> <https://docs.microsoft.com/en-us/azure/digital-twins/overview> (accessed 201120)

<sup>74</sup> <https://www.esipfed.org/about> (accessed 201120)

<sup>75</sup> <https://en.wikipedia.org/wiki/JSON-LD> (accessed 201120)

<sup>76</sup> <https://ai.googleblog.com/2020/08/an-analysis-of-online-datasets-using.html> (accessed 201120)

<sup>77</sup> <https://www.eea.europa.eu/highlights/robust-monitoring-and-targets-are> (accessed 281020)

<sup>78</sup> <https://scottishwildlifetrust.org.uk/news/route-map-to-1-billion-for-nature-conservation-published/> (accessed 231120)

concept of digital twins<sup>79</sup>, UNEP (David Jensen) are coordinating a global digital ecosystem<sup>80</sup>, UKRI have established the NERC ‘Constructing a Digital Environment’ programme<sup>81</sup>, and Microsoft are investing heavily in bridging the gap between computer developers, scientists, and wider stakeholders in their vision for a planetary computer<sup>82</sup>. The geospatial aspects of the digital environments are the focus of the UK Geospatial Commission. A draft list of key technological components for creating digital environments are summarised in Table 1. In recent presentations, David Jensen (UNEP) provided a list based on eight core digital technologies: cloud and edge computing; artificial intelligence and machine learning; internet of things; platforms and social media; blockchain and distributed databases; open source and commercial software; mobile phone applications; and satellites, drones, and sensors.

Access to relevant data through consortiums like Public Sector Geospatial Agreement (PSGA)<sup>83</sup> with the UK Ordnance Survey, reduces friction in terms of data access and so enabling the work of organisations like SEPA and NatureScot. Box 2 provides an overview of the UK’s Ordnance Survey innovations in relation to data pipelines, digital environments, and increasing the ability of their users to find and use their data products.

Interdisciplinary collaborations are vital in developing future technologies in ecology (Joppa 2015). Joppa (2015) called for the conservation sector “to build a community of practice, come together to define key technology challenges and work with a wide variety of partners to create, implement, and sustain solutions” to realise the potential of digital technologies for biodiversity conservation. This message was repeated by Berger-Tal and Lahoz-Monfort (2018) who suggested it was time for the conservation community to, not just consume technology, but become innovation leaders though working with technologists and others to create novel technologies that can provide conservation tools and solutions. Some researchers and conservationists have said that to enable the potential of digital technology to increase our capacity to conserve our planet’s biodiversity, there is need for an international conservation technology organisation that would: provide vision and leadership, coordinate and deliver international development and deployment of conservation technology, and enable integration into biodiversity conservation policies from local to global scales through improved environmental monitoring (Lahoz-Monfort et al., 2019). Bridging the gap in how data and digital technology can improve our environmental understanding, is required for all – not just ecological researchers.

A review by Sun and Scanlon (2019) of over 1000 scientific papers on ‘how big data and machine learning can benefit environment and water management’ identified: several challenges including data cleansing and governance; that solutions need to be designed and produced by people who understand the problem and context; and that greater collaboration is needed between governments (and its agencies), domain experts, data scientists, the general public, and the private sector. In a Scottish context, then the Scottish Government needs to enable this collaboration in support of its sustainability and green recovery goals.

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<sup>79</sup> <https://www.cdbb.cam.ac.uk/what-we-do/national-digital-twin-programme> (accessed 221120)

<sup>80</sup> <https://medium.com/@UNDP/the-pressing-need-for-a-global-digital-ecosystem-aa10a9f8df56> (accessed 221120)

<sup>81</sup> <https://nerc.ukri.org/innovation/activities/environmentaldata/digitalenv/> (accessed 231120) (accessed 221120)

<sup>82</sup> <https://innovation.microsoft.com/en-us/planetary-computer> (accessed 221120)

<sup>83</sup> <https://www.ordnancesurvey.co.uk/business-government/public-sector-geospatial-agreement> (accessed 221120)

## Box 2. The UK Ordnance Survey's use of data pipelines, digital environments, and communities of practice

The work of the UK Ordnance Survey to update their mapping products using aerial imagery to monitor half a billion geospatial features provides some impressive examples of data pipelines. Their mission is they want their customers to trust, find and use OS data. Enabling them to connect data through the language of location for greater insights, better decisions and smarter outcomes. Recently, they shared newly developed set of data principles. These principles ensure we treat data as a valuable asset and give it the time, resources and prioritisation it needs. They closely align to the FAIR principles (Findable, Accessible, Interoperable and Reusable). The principles are grouped into the three main themes of 'trust', 'easy to find' and 'easy to use'.

Over the past couple of years, the Ordnance Survey has been working hard to improve how people can find and use their data, for example they have improved their developer portals

<https://www.ordnancesurvey.co.uk/business-government/developers>.

### 2.1.2 Examples of innovations in environmental monitoring

There are a wide range of digital social innovations in environmental monitoring from volunteer-based projects, to greater use of remote sensing, and development of data pipelines in place-based studies from farm to regional scales. In this section, five examples of these innovations are presented. In addition to these five examples, there are a range of innovations in the monitoring of marine and terrestrial habitats, for example JNCC and MSS (Marine Scotland Science) survey of the Pobie Bank Reef Special Area of Conservation off the East coast of Shetland<sup>84</sup>.

#### 2.1.2.1 Biological monitoring: volunteer-based/citizen science

The purpose of the Scottish Biodiversity Information Forum (SBIF) review was to determine the optimum infrastructure for biological recording in Scotland, fulfilling the original vision of SBIF: "high quality species and habitat data will be collected and managed through a sustainable, coordinated and integrated local and national framework of organisations, partnerships and initiatives. These data will be available to ensure that Scotland's biodiversity, ecosystems and people benefit." Rachel Tierney, SBIF Development Officer, in a blog post<sup>85</sup> showed how the 24 recommendations from the SBIF review fitted together and their practical implications. "The SBIF Review is structured around five outcomes that address how, by 2025, we can transform funding for biological recording, simplify and integrate data flows, redesign the biodiversity data services we offer, and transform the structure and governance of the organisations delivering these services to ensure complete geographic coverage across Scotland."

Smartphones are often at the heart of community-based environmental monitoring in the UK, in part due to about 83% of the population owning a smart phone<sup>86</sup>. A review of smartphones for community and citizen science environmental monitoring, to improve understanding of how and when they can be useful, found that there is a need for improved awareness of the actual costs of app development, monitoring, and implementation; and the need be clearer about the role of individuals and partnerships in using apps in conservation impacts (Andrachuk, 2019).

<sup>84</sup> <https://jncc.gov.uk/about-jncc/jncc-blog/archive/pobie-bank-reef-blog-4/> (accessed 101220)

<sup>85</sup> <https://nbn.org.uk/blogs/sbif-blog/picturing-the-future/> (accessed 281020)

<sup>86</sup> [https://en.wikipedia.org/wiki/List\\_of\\_countries\\_by\\_smartphone\\_penetration](https://en.wikipedia.org/wiki/List_of_countries_by_smartphone_penetration) (accessed 221120)

Jennifer Gabrys leads a range of Citizen Sense<sup>87</sup> projects, with the aim to investigate environmental sensing technologies and citizen engagement to enable new modes of environmental awareness and practice. In a recent commentary Gabrys (2020) discussed how the digitalization of forests as part of wider area of smart environments, can change our understanding of forests and enable new practices for addressing environmental change. Five practices were identified in relation to the concept of 'smart forests':

1. Increasing use of digital technologies for observing forests.
2. Datafication -forests are now sites of intensive data production.
3. Greater use of automation and optimization e.g. to detect and analyse forest fires.
4. Increased levels of participation through initiatives like Global Forest Watch and citizen science projects.
5. Changes in the regulation of forests due to the proliferation of digital technologies.

Due to the large number of citizen science projects and resources projects with web sites like EU-Citizen.Science have been set up to aid sharing and reuse<sup>88</sup>. The EU-Citizen.Science project has a vision that Citizen Science becomes an appreciated and widely established means for the democratization of science in Europe.

include collecting information on land cover and land use

#### *2.1.2.2 Monitoring the presence of species through eDNA*

Environmental DNA (eDNA) is attracting increased attention for its potential for environmental monitoring. The term eDNA originated in the field of microbiology (Ogram et al., 1987). In the past decade there has been increased interest in the potential of eDNA to detect macroorganisms since early studies on the persistence of American bullfrog (*Lithobates catesbeianus*) (Ficetola et al., 2008). Though the extraction of DNA from a range of environmental matrices has been carried out for decades, increases in the numbers of studies focussed on detection of DNA in environmental matrices led, in 2019, to a new journal focussed on Environmental DNA (Bernatchez, 2019). A review of 438 published eDNA studies detecting aquatic macroorganisms showed the most common procedures were filtration and subsequent extraction/purification using a DNeasy Blood and Tissue DNA extraction kit (Qiagen, Hilden, Germany) or PowerWater DNA Extraction Kit (Qiagen) (Tsuji et al., 2019). A recent meta-analysis on the potential of eDNA to detect the abundance of a species in a given environment, showed that further research is needed before eDNA can be used for quantifying abundance (Yates et al., 2019). Another analysis of 160 eDNA freshwater studies found inconsistent reporting of metadata in eDNA studies, with habitat being most reported whereas environmental conditions at time of sampling being least reported (Nicholson et al., 2020). The authors said the lack of consistent metadata based standardised reporting guidelines reduced replicability of research projects and would limit industry and government use of eDNA surveys. A study of the temporal and spatial variation of fish eDNA compared with spatial sampling of fish in Windermere (UK), found broad consistency in terms of species detection and abundance, and highlighted seasonal performance and biases of eDNA surveys (Lawson Handley et al., 2019).

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<sup>87</sup> <https://citizensense.net/> (accessed 221120)

<sup>88</sup> <https://eu-citizen.science/> (accessed 101220)

### *2.1.2.3 Monitoring peatland condition*

The JNCC have produced a recent report<sup>89</sup> on how earth observation of peatland habitats can be carried out at different scales. They explored how bare peat cover could be detected in automated processes (data pipeline/workflow) from high resolution aerial (Ariel Photography for Great Britain 25 and 50cm every 3-5 years) and commercial satellite (Pleiades-1A daily 2m resolution) imagery using machine learning. The analysis was carried out in the Peak District using imagery from June 2018. Though it was “possible to partially automate a process of deriving bare peat pixels from high-resolution aerial photography, through thresholding indices derived from the imagery” it was “not possible to develop a thresholding rule for the Pleiades satellite imagery with the indices we trialled, due to the overlap of indices signatures between areas of vegetated and bare peat”<sup>90</sup>. Their process was heavily dependent on manual digitising of vegetated and non-vegetated areas by experts.

### *2.1.2.4 Monitoring, reporting, and verification of agricultural greenhouse gas emissions*

There is a need to understand the relationships between land and climate change, including the storage of carbon in soils and vegetation and related greenhouse gas (GHG) emissions<sup>91</sup>. As part of the Race to Zero<sup>92</sup> global campaign to encourage support for a healthy, resilient, and zero carbon recovery, the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) hosted an event with the UK Foreign, Commonwealth, and Development Office (FCDO) that highlighted the need to better understand how we can transform food systems to address environmental challenges. The monitoring, reporting, and verification of emissions is central to carbon pricing and management mechanisms, and a 2015 review concluded “one would intuitively encourage quantitative requirements on emissions uncertainty, together with an incentive to improve precision. Most often, this is only partially applied, if at all” (Bellassen et al., 2015). A NERC Digital Environment funded demonstration project ‘RETINA’ is seeking to improve understanding of soil carbon change by linking sensors, edge and high-performance computing-based data analysis, and visualisation to meet farmer and policymaker information needs, in support of net-zero GHG emissions targets<sup>93</sup>.

### *2.1.2.5 Forth Environmental Resilience Array*

The recently announced<sup>94</sup> Forth Environmental Resilience Array, led by Professor Andrew Tyler at University of Stirling, seeks to develop and provide “a ‘living laboratory’ –capturing, processing, and sharing data from across Forth Valley using EE’s 5G network. It uses sensors, satellite data, and artificial intelligence to provide vital information on water quality and other factors to inform decisions that could provide major economic and sustainability benefits to the area”. “In phase one, working with BT and regional stakeholders, they will demonstrate how providing additional information on the quality and quantity of water across the continuum of inland to coastal waters can support and inform the actions of our project use case partners.”

## 2.1.3 Environmental monitoring data pipelines as part of wider social processes involved in local to national-level adaptive management

Environmental monitoring data pipelines and digital environments are only part of the solution to supporting a green technology-led recovery. In a recent summary of landscape-level adaptive management for environmental, economic, and social outcomes. The authors suggested 14

<sup>89</sup> <https://jncc.gov.uk/news/earth-observation/> (accessed 221120)

<sup>90</sup> <https://data.jncc.gov.uk/data/958df51f-2e7c-4d2b-92f0-eac84c2a86af/JNCC-Report-667-FINAL-WEB.pdf> (accessed 221120)

<sup>91</sup> <https://www.ipcc.ch/srccl/> (accessed 221120)

<sup>92</sup> <https://unfccc.int/climate-action/race-to-zero-campaign> (accessed 221120)

<sup>93</sup> <https://www.hutton.ac.uk/news/groundbreaking-research-develop-soil-carbon-sequestration-monitoring-system> (accessed 221120)

<sup>94</sup> <https://www.stir.ac.uk/news/2020/09/world-leading-living-laboratory-for-central-scotland/>(accessed 281020)

recommendations based on: understand the situation, direct stakeholders, and shared purpose; focus on the social relationships of landscape-level management; and assess ecological, economic, and social outcomes at every step of the adaptive management cycle<sup>95</sup>.

Innovations in environmental monitoring include social innovations like the establishment of the Ecological Continuity Trust in 2008<sup>96</sup> and UK Terrestrial Evidence Partnership of Partnerships (UKTEPoP)<sup>97</sup>, and the Scottish Biodiversity Information Forum (SBIF) review<sup>98</sup>; as well as technical innovations e.g. Copernicus Sentinel satellite missions<sup>99</sup>. Where social innovations are new social practices that aim to meet societal needs in a better way than the existing solutions. Internationally the GEO BON<sup>100</sup> working group on data is now actively considering the standards for data products to be badged as Essential Biological Variables (EBVs), and these could be used to aid interoperability between data products created by UKTEPoP members.”

#### 2.1.4 Building on SEWeb and connecting with UNEP’s Digital Transformation programme

In 2011, SEPA and partners secured initial funding (over two million Euros) from the European Commission to establish Scotland’s environment web project with four key objectives: develop an inclusive partnership programme to bring together data providers and data users; promote the expansion of a European Shared Environmental Information System; to improve effectiveness of policy development and targeting of environmental measures; and to engage the public by providing access to high quality on-line interactive resources to promote better understanding of the environment<sup>101</sup>. Since 2011, an impressive range of interactive feature and datasets have been added to SEWeb from air quality to water quality and a wide range of educational resources.

Early in 2021, the United Nations Environment Programme (UNEP) will complete negotiations with member states (funders) to fund a new four-year Digital Transformation programme (2022-2026), led by David Jensen (who currently leads the UNEP Digital Task Force). This has four key strategic actions to speed and scale climate, nature and pollution actions: digital ecosystem for the planet, transformative digital applications, digital literacy and e-governance, and a digitally enabled UNEP. This is based on the pivotal moment in history of the need to utilise advances in digital technologies and data to address the climate, nature, and pollution crises. There are four challenges to delivering this:

1. Data is highly fragmented, unstructured and of variable quality.
2. Increasing need for public-private collaboration to transform data into insights that can influence economic incentives and behaviours.
3. Must close the digital divide and strengthen digital literacy and engagement by all actors.
4. Our own institutions must undergo their own digital transformation processes and set priorities.

We are discussing with David Jensen how we can contribute to their Digital Transformation programme.

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<sup>95</sup> <https://sefari.scot/research/recommendations-for-landscape-level-adaptive-management-for-ecological-economic-and-social> (accessed 281020)

<sup>96</sup> <https://www.ecologicalcontinuitytrust.org/> (accessed 281020)

<sup>97</sup> <https://jncc.gov.uk/our-work/uktepop/> (accessed 281020)

<sup>98</sup> <https://nbn.org.uk/about-us/where-we-are/in-scotland/the-sbif-review/> (accessed 281020)

<sup>99</sup> <https://sentinel.esa.int/web/sentinel/home> (accessed 281020)

<sup>100</sup> <https://geobon.org/>

<sup>101</sup> <https://www.environment.gov.scot/about-us/life-project-archive/project-archive/> (accessed 101220)



## 2.2 Digital social innovations in monitoring to provide collective intelligence

Nesta has led a project for the European Commission on digital social innovation between 2012 to 2019. In this video<sup>102</sup> Peter Baeck (Head of Nesta’s Centre for Collective Intelligence Design) talks about how digital social innovation (also called civic tech) is about using technology to mobilise people to solve some of society’s biggest challenges. Where collective intelligence is created when people work together, often with the help of technology, to mobilise a wider range of information, ideas, and insights to address a challenge (see Box 3). Fundamentally, it is about ‘becoming smarter together’ with people, data, and technology. For example, CivicAI<sup>103</sup> explores how AI can enhance collective intelligence in relation to climate crisis mitigation and adaptation.

Society is experiencing a digital transformation from local to global levels. In his recent book Thomas Siebel said this was being driven by how Internet of Things (IoT) sensors, and the data generated, ‘elastic’ cloud computing, and the growth in artificial intelligence/machine learning (AI/ML) including predictive analytics (Siebel, 2019). He has recently launched the C3.ai Digital Transformation Institute<sup>104</sup> with Microsoft and several leading US universities, including MIT and Stanford, to accelerate the application of AI to speed the pace of digital transformation in business, government, and society.

In Scotland, the pace of digital transformation is illustrated by several initiatives over the past year including Digital Planning<sup>105</sup> (Scottish Government’s digital transformation of the planning system) and 5G for Scotland Strategy<sup>106</sup> (Scottish Government’s strategy for the potential of 5G and related services to create new jobs and business opportunities). At a UK level, there has been recent publication of the Geospatial Strategy<sup>107</sup> (sets out a coordinated approach to unlock economic, social and environmental value from geospatial data), and the UK Water Partnership’s (including Scottish Government, Scottish Water, and CREW) white paper and call to action ‘Digital Water – capitalising on the commercial opportunities for UK Plc’<sup>108</sup>. Scotland’s innovation centres especially The Data Lab and CENSIS are continuing to support Scotland’s digital transformation.

Box 3. Collective intelligence in a typical innovation process (Nesta’s collective intelligence design playbook)

<p><b>Learn and adapt:</b> Monitor the implementation of initiatives by involving citizens in generating data and share knowledge to improve the ability of others.</p>	<p><b>Understand problems:</b> generate contextualised insights, facts, and information on the dynamics of a situation.</p>
<p><b>Decide and act:</b> Make decisions with, or informed by, collaborative input from a wide range of people and/or relevant experts.</p>	<p><b>Seek solutions:</b> find novel approaches or tested solutions from elsewhere. Or incentivise innovators to create new ways of tackling the problem.</p>

The wide spread use of smartphones and map based web pages means that the average citizen, in high income countries like Scotland, is equipped and familiar with the technology to collect environmental data and to view and explore it on mobile/web applications. These changes in the

<sup>102</sup> <https://www.youtube.com/watch?v=hg9oO1LeNC0> (accessed 281020)

<sup>103</sup> <https://civic-ai.org/> (accessed 281020)

<sup>104</sup> <https://c3dti.ai> (accessed 221120)

<sup>105</sup> <https://www.transformingplanning.scot/digital-planning/> (accessed 221120)

<sup>106</sup> <https://www.gov.scot/publications/forging-digital-future-5g-strategy-scotland/> (accessed 221120)

<sup>107</sup> <https://www.gov.uk/government/publications/unlocking-the-power-of-locationthe-uks-geospatial-strategy> (accessed 221120)

<sup>108</sup> <https://www.theukwaterpartnership.org/initiatives/digital-water> (accessed 221120)

capacity of individuals, should not be underestimated in terms of increasing the potential of innovations in environmental monitoring. All technologies have advantages and limitations including challenges in implementing them as illustrated by Larson et al. (2020) in their review of technologies for the early detection of invasive species. In a recent paper by Jennifer Gabrys (2020) on the digitisation of forests, said it is not only changing our understanding of them but also leading to new practices for addressing environmental change. She highlighted that one potential problem of the growth in ‘smart environments’ is the data that is collected, stored, and operationalized to manage these spaces, requires attention to the social–political relations and potential inequalities that may emerge through these digital systems.

### 3. Draft vision, suggested missions, and recommended actions to deliver a resilient, green, and digital Scotland

The First Minister of Scotland and the President of the European Commission have both set out common visions for twin green and digital transitions for Scotland and the European Union, respectively. To address the local to global environmental, economic, and social challenges we are facing in 2020. In Scotland, the National Performance Framework is already aligned with the UN Sustainable Development Goals<sup>109</sup>. Recently, UNEP have set out a 10-year action agenda for harnessing data and digital transformation to accelerate environmental sustainability across three areas: climate action, nature action, and chemicals and pollution action.

**Our draft vision, suggested missions, and recommended actions are just that ‘suggestions’.**

These need to be shaped and owned by a wider environmental monitoring community, spanning public and private organisations, building on existing initiatives like the SBIF review of biological monitoring and SEWeb, and that we work closely with related international activities, for example UNEP’s Digital Transformation programme, to realise our collective ambition of improving our use and management Scotland’s rural, urban, and marine environments.

This report sets out a **draft vision for digital social innovations in environmental monitoring** to address local to global scale environmental challenges and support a green recovery. Harnessing shared understanding and common purpose across Scotland’s monitoring communities to enable people to work together, often with the help of technology, to mobilise a wider range of information, ideas, and insights to address local to global scale environmental challenges.

Our draft vision is for data-information-knowledge, based on environmental monitoring data flows, to be **findable and accessible** to whoever needs it, **interoperable with existing and new applications and workflows/data pipelines**, and that it is **widely reused** from individual to national level decision making to **improve the climate change, biodiversity loss, and unsustainable use of natural resources challenge situations** as part of a green technology-led recovery.

We suggest our draft vision could be delivered through a series of four linked missions, one cross-cutting integrative mission and three targeted missions to improve the climate change, biodiversity loss, and unsustainable use of natural resources challenge situations. These are presented alongside

<sup>109</sup> <https://nationalperformance.gov.scot/> (accessed 221120)

four sets of recommended actions. See Box 4 to learn more about missions and their recent use in public policy strategies and initiatives. Figure 1 shows the nested nature of the four draft missions.

### 3.1 Suggested mission 1: Establish a community of practice by 2021 to build Scotland's capacity in environmental monitoring data flows and digital environment

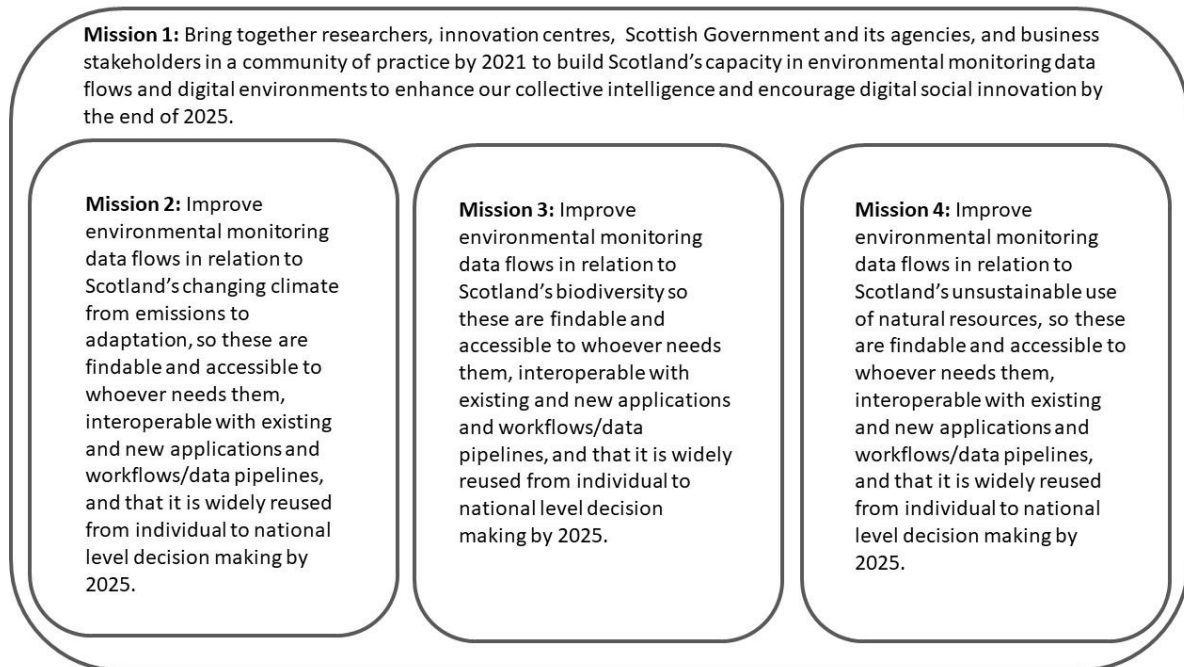


Figure 1. Relationships between the four draft missions.

#### **Suggested mission 1 recommended actions:**

**Suggested mission 1:** Bring together researchers, innovation centres, Centres of Expertise, Scottish Government and its agencies, and business stakeholders in a community of practice by 2021 to build Scotland's capacity in environmental monitoring data flows and digital environments to enhance our collective intelligence and encourage digital social innovation by the end of 2025.

**1.1 Establish and fund an open and inclusive national steering group in 2021** spanning research organisations e.g. HEIs and SEFARI research institutes, Scotland's innovation centres e.g. CENSIS and the Data Lab, SEWeb, Scottish Government and its agencies e.g. NatureScot and SEPA, and businesses and their representatives. This group will refine this vision and missions and establish a detailed plan of work to 2025.

**1.2 Develop working relationships with UNEP's Digital Transformation programme during 2021** building on initial discussions with David Jensen, learning more about their plans and how we can contribute to their vision.

**1.2 Fund an individual during 2021** with technical knowledge of environmental monitoring data flows and digital environments and knowledge about policy and other use cases to deliver the vision through these missions through working with international partners e.g. UNEP.

**1.3 Create online resources in 2021** to raise the profile of this 2020-2025 strategy, through providing links to relevant resources and case studies of digital social innovations in environmental monitoring in Scotland and internationally.

**1.4 Share information in 2021 on advancements in the fields of sustainable finance and nature-related financial disclosures** and related initiatives in support of Scotland's green recovery.

### 3.2 Suggested mission 2: Improve FAIR environmental monitoring data flows in relation to Scotland's changing climate including emissions, adaptation, and finance

**Suggested mission 2:** Improve environmental monitoring data flows in relation to Scotland's changing climate from emissions to adaptation, so these are findable and accessible to whoever needs them, interoperable with existing and new applications and workflows/data pipelines, and that it is widely reused from individual to national level decision making by 2025.

#### **Suggested mission 2 recommended actions:**

**2.1 Establish a community of practice and fund a coordinator in 2021** on environmental monitoring data flows in relation to Scotland's changing climate from emissions to adaptation spanning research organisations e.g. HEIs and SEFARI research institutes, Scotland's Centres of expertise e.g. CxC and CREW, Scotland's innovation centres e.g. CENSIS and the Data Lab, Scottish Government and its agencies e.g. NatureScot and SEPA, and businesses and their representatives. This community will integrate and build on existing initiatives and needs.

**2.2 Assess public policy needs** in terms of environmental monitoring data flows in relation to Scotland's changing climate from emissions to adaptation and what are the gaps and barriers to access with existing provision of monitoring data by 2022.

**2.3 Assess business needs** in terms of environmental monitoring data flows in relation to Scotland's changing climate including emissions, adaptation and finance, and what are the gaps with existing provision of monitoring data by 2022.

**2.4 Encourage and fund digital social innovation of environmental monitoring data** flows in relation to Scotland's changing climate from emissions to adaptation by 2025.

### 3.3 Suggested mission 3: Improve FAIR environmental monitoring data flows in relation to Scotland's biodiversity

**Suggested mission 3:** Improve environmental monitoring data flows in relation to Scotland's biodiversity so these are findable and accessible to whoever needs them, interoperable with existing and new applications and workflows/data pipelines, and that it is widely reused from individual to national level decision making by 2025.

#### **Suggested mission 3 recommended actions:**

**3.1 Build on the SBIF community of practice and fund a coordinator in 2021** on environmental monitoring data flows in relation to Scotland's biodiversity spanning existing biological record infrastructure partners (building on SBIF review), as well as additional research organisations e.g. HEIs and SEFARI research institutes, Scotland's Centres of expertise e.g. ClimateXChange<sup>110</sup> and

<sup>110</sup> <https://www.climatexchange.org.uk/> (accessed 101220)

CREW (Centre of Expertise for Waters)<sup>111</sup>, Scotland's innovation centres e.g. CENSIS and the Data Lab, and businesses and their representatives. This community will integrate and build on the SBIF review, its recommendations, and recent progress. It is envisaged that NatureScot will lead this community.

**3.2 Work with partners e.g. NatureScot and NBN Trust to improve FAIR data flows** of biological species data by 2023.

**3.3 Encourage and fund digital social innovation of environmental monitoring data flows** in relation to Scotland's biodiversity by 2025.

3.4 Suggested mission 4: Improve FAIR environmental monitoring data flows in relation to Scotland's unsustainable use of natural resources

**Suggested mission 4:** Improve environmental monitoring data flows in relation to Scotland's unsustainable use of natural resources, so these are findable and accessible to whoever needs them, interoperable with existing and new applications and workflows/data pipelines, and that it is widely reused from individual to national level decision making by 2025.

**Suggested mission 4 recommended actions:**

**4.1 Build on SEPA's One Planet Prosperity community of practice and fund a coordinator in 2021** on environmental monitoring data flows in relation to Scotland's unsustainable use of natural resources and increase involvement from research organisations e.g. HEIs and SEFARI research institutes, Scotland's Centres of expertise e.g. CxC and CREW, Scotland's innovation centres e.g. CENSIS and the Data Lab, and businesses and their representatives. This community will integrate and build on SEPA's current work. It is envisaged that SEPA will lead this community.

**4.2 Work with partners to improve FAIR data flows** in relation to natural resource use in Scotland by 2023.

**4.3 Encourage and fund digital social innovation of environmental monitoring data flows** in relation to Scotland's natural resource use by 2025.

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<sup>111</sup> <https://www.crew.ac.uk/> (accessed 101220)

#### Box 4. What are missions, why needed, and how are they being used?

**What are missions?** To help unlock the imagination and creativity of citizens, missions should aim to solve problems using collective intelligence. This means identifying challenges, co-creating solutions and evaluating policies through a transparent and meaningful process with the relevant actors (see Nesta’s Open Policymaking Playbook). The resulting missions must be concrete and time bound.

“Missions work with a network of different institutions, and use a suite of coordinated interventions, to tackle different aspects of the grand challenge in a direct way. The UK is already using this approach for its Grand Challenges in the Industrial Strategy. “

**Why are missions needed?** “The problem isn’t a lack of policies to fix many of these issues, but there is a lack of coordination within government and the skills system to bring together the solutions that could tackle these challenges. This is where a mission-oriented approach can help.”

**How are missions being used?** Professor Mariana Mazzucato at the Institute of Innovation and Public Purpose, UCL, has written extensively on missions. Professor Mazzucato has advised the Scottish Government on establishing the Scottish National Investment Bank and its mission-based approach.

The UK Geospatial Strategy 2020 to 2025 set out a vision that by 2025 the UK will have a coherent national location data framework. Their vision was to focus efforts around four missions: 1- Promote and safeguard the use of location data; 2- Improve access to better location data; 3- Enhance capabilities, skills, and awareness; and 4- Enable innovation.

## Acknowledgements

This research was funded through the SEFARI Fellowship on ‘Innovations in Environmental Monitoring’. We would like to thank the Steering Group members for enabling and guiding this work. We would also like to thank a wide range of colleagues who provided their time to discuss this project. A range of colleagues within SEPA, NatureScot, CREW, and the James Hutton Institute provided valuable feedback on this report.

## References

- Aggestam, Filip. 'Setting the Stage for a Shared Environmental Information System'. *Environmental Science & Policy*, vol. 92, Feb. 2019, pp. 124–32. doi:10.1016/j.envsci.2018.11.008.
- Andrachuk, Mark, et al. 'Smartphone Technologies Supporting Community-Based Environmental Monitoring and Implementation: A Systematic Scoping Review'. *Biological Conservation*, vol. 237, Sept. 2019, pp. 430–42. doi:10.1016/j.biocon.2019.07.026.
- Angelstam, Per, et al. 'LTSER Platforms as a Place-Based Transdisciplinary Research Infrastructure: Learning Landscape Approach through Evaluation'. *Landscape Ecology*, vol. 34, no. 7, July 2019, pp. 1461–84. doi:10.1007/s10980-018-0737-6.
- Bellassen, Valentin, et al. 'Monitoring, Reporting and Verifying Emissions in the Climate Economy'. *Nature Climate Change*, vol. 5, no. 4, Apr. 2015, pp. 319–28. doi:10.1038/nclimate2544.
- Berger-Tal, Oded, and José J. Lahoz-Monfort. 'Conservation Technology: The next Generation'. *Conservation Letters*, vol. 11, no. 6, Nov. 2018, p. e12458. doi:10.1111/conl.12458.
- Bernatchez, Louis. 'Welcome to Environmental DNA!' *Environmental DNA*, vol. 1, no. 1, May 2019, pp. 3–4. doi:10.1002/edn3.18.
- Craglia, Max, et al. 'Digital Earth 2020: Towards the Vision for the next Decade'. *International Journal of Digital Earth*, vol. 5, no. 1, Jan. 2012, pp. 4–21. doi:10.1080/17538947.2011.638500.
- Ficetola, Gentile Francesco, et al. 'Species Detection Using Environmental DNA from Water Samples'. *Biology Letters*, vol. 4, no. 4, Aug. 2008, pp. 423–25. doi:10.1098/rsbl.2008.0118.
- Gabrys, Jennifer. 'Smart Forests and Data Practices: From the Internet of Trees to Planetary Governance'. *Big Data & Society*, vol. 7, no. 1, Jan. 2020, p. 205395172090487. doi:10.1177/2053951720904871.
- Gore, Al. *Earth in the Balance: Ecology and the Human Spirit*. Plume, 1992.
- Joppa, Lucas N. 'Technology for Nature Conservation: An Industry Perspective'. *Ambio*, vol. 44, no. S4, Nov. 2015, pp. 522–26. doi:10.1007/s13280-015-0702-4.
- Lahoz-Monfort, José J., et al. 'A Call for International Leadership and Coordination to Realize the Potential of Conservation Technology'. *BioScience*, vol. 69, no. 10, Oct. 2019, pp. 823–32. doi:10.1093/biosci/biz090.
- Larson, Eric R., et al. 'From eDNA to Citizen Science: Emerging Tools for the Early Detection of Invasive Species'. *Frontiers in Ecology and the Environment*, vol. 18, no. 4, May 2020, pp. 194–202. doi:10.1002/fee.2162.
- Lawson Handley, Lori, et al. 'Temporal and Spatial Variation in Distribution of Fish Environmental DNA in England's Largest Lake'. *Environmental DNA*, vol. 1, no. 1, May 2019, pp. 26–39. doi:10.1002/edn3.5.
- Lovett, Gary M., et al. 'Who Needs Environmental Monitoring?' *Frontiers in Ecology and the Environment*, vol. 5, no. 5, June 2007, pp. 253–60. doi:10.1890/1540-9295(2007)5[253:WNEM]2.0.CO;2.
- McQuivey, James. *Digital Disruption: Unleashing the Next Wave of Innovation*. Forrester Research, Incorporated, 2013.

- Nicholson, Andrew, et al. 'An Analysis of Metadata Reporting in Freshwater Environmental DNA Research Calls for the Development of Best Practice Guidelines'. *Environmental DNA*, vol. 2, no. 3, 2020, pp. 343–49. Wiley Online Library, doi:<https://doi.org/10.1002/edn3.81>.
- Ogram, Andrew, et al. 'The Extraction and Purification of Microbial DNA from Sediments'. *Journal of Microbiological Methods*, vol. 7, no. 2–3, Dec. 1987, pp. 57–66. doi:10.1016/0167-7012(87)90025-X.
- Siebel, Thomas M. *Digital Transformation: Survive and Thrive in an Era of Mass Extinction*. RosettaBooks, 2019.
- Sun, Alexander Y., and Bridget R. Scanlon. 'How Can Big Data and Machine Learning Benefit Environment and Water Management: A Survey of Methods, Applications, and Future Directions'. *Environmental Research Letters*, vol. 14, no. 7, July 2019, p. 073001. doi:10.1088/1748-9326/ab1b7d.
- The European Environment — State and Outlook 2020: Knowledge for Transition to a Sustainable Europe — European Environment Agency. <https://www.eea.europa.eu/soer/2020>. Accessed 23 Nov. 2020.
- Tsuji, Satsuki, et al. 'The Detection of Aquatic Macroorganisms Using Environmental DNA Analysis— A Review of Methods for Collection, Extraction, and Detection'. *Environmental DNA*, vol. 1, no. 2, 2019, pp. 99–108. Wiley Online Library, doi:<https://doi.org/10.1002/edn3.21>.
- Waylen, Kerry A., et al. 'Policy-Driven Monitoring and Evaluation: Does It Support Adaptive Management of Socio-Ecological Systems?' *Science of The Total Environment*, vol. 662, Apr. 2019, pp. 373–84. doi:10.1016/j.scitotenv.2018.12.462.
- Wehn, Uta, and Abeer Almomani. 'Incentives and Barriers for Participation in Community-Based Environmental Monitoring and Information Systems: A Critical Analysis and Integration of the Literature'. *Environmental Science & Policy*, vol. 101, Nov. 2019, pp. 341–57. doi:10.1016/j.envsci.2019.09.002.
- Wilkinson, Mark D., et al. 'The FAIR Guiding Principles for Scientific Data Management and Stewardship'. *Scientific Data*, vol. 3, no. 1, Dec. 2016, p. 160018. doi:10.1038/sdata.2016.18.
- Yates, Matthew C., et al. 'Meta-Analysis Supports Further Refinement of EDNA for Monitoring Aquatic Species-Specific Abundance in Nature'. *Environmental DNA*, vol. 1, no. 1, 2019, pp. 5–13. Wiley Online Library, doi:<https://doi.org/10.1002/edn3.7>.