Emerging Technologies in the Ecology and Conservation Sectors

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by

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Abstract

The technological landscape in ecology is rapidly advancing, but current literature often overlooks its practical applications within the industry. This study aimed to fill this gap by examining and quantifying perspectives from ecology professionals on the significance of emerging technologies—defined here as tools and methods that are novel in design, application, or capability and reflect the ongoing digitization within ecological practice. A mixed-method approach combining interviews and surveys captured industry insights, revealing that while emerging technologies are widely used, their definition varies across sectors. Key tools identified include thermal and infrared cameras, environmental DNA (eDNA) analysis, drones, bioacoustics, and artificial intelligence (AI). These innovations are largely recognized for enhancing efficiency, particularly by automating data collection and analysis, results in more time for ecologists to devote to conservation projects and goals. Cost-efficiency was noted as both a benefit and a constraint, with technologies such as drones and eDNA representing high-return investments in their accuracy and resolution. However, as ecological technologies become more developed and specialized, costs increase initially, creating a need for more accessible, open-source, and consumer-grade solutions to be explored more efficiently, as seen with drones and infrared cameras in the past. Although some participants expressed concerns about integrating untested technologies, standardization across the field was recommended for successful technological integration. Increased support for targeted training of early-career ecologists and continued upskilling for experienced professionals are essential for facilitating the effective assimilation of ecologists and technology. Graduates should be made aware of their technological options, how to understand their outputs, and the conceptual knowledge necessary to apply both practical and analytical technologies.

Lay summary

The field of ecology is rapidly evolving with new technologies, but these advancements are not always fully represented in current literature. This project set out to bridge this knowledge gap by exploring and quantifying the value of emerging technologies based on insights from industry professionals. Emerging technologies—often digital, innovative tools or methods—are varied and can mean different things to different people in the ecological sector. This study found that the industry widely uses emerging technologies like thermal and infrared cameras, revolutionary methods such as eDNA (environmental DNA) analysis, and artificial intelligence. These technologies offer many benefits, particularly by saving time through automated data collection and analysis. While the cost of technology can be both an advantage and a challenge, some tools, like drones and eDNA, offer great value due to their precision and cost-effectiveness. As advanced tools become more specialized, their costs rise, leading experts to call for more open-source and affordable options for the industry. Though there are some hesitations about integrating new technologies, standardization is encouraged, along with increased training for early career ecologists and continued support for professionals. This approach aims to ensure these tools are used effectively, enhancing outcomes in ecology and conservation.

Declarations

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed: [redacted]

Date: 31/10/24

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

Signed: [redacted]

Date: 31/10/24

I hereby give consent for my thesis, if accepted, to be available for electronic sharing

Signed: [redacted]

Date: 31/10/24

The University's ethical procedures have been followed and, where appropriate, that ethical approval has been granted.

Signed: [redacted]

Date: 31/10/24

Statement of Expenditure

Category	Item	Description	Cost
Software subscription	Otter.AI Pro Subscription	Initial monthly purchase of Otter.AI Pro Subscription	£10.00
Software subscription	Otter.AI Business Subscription	Movement to Otter.AI Business Subscription, accounting for payment plan change, as the previous plan did not account for necessary features for analysis.	£13.06
Software subscription	Otter AI Business Subscription	Continuation of monthly subscription for Otter.AI Business Plan.	£22.62
Software subscription	NVivo 15 subscription – per seat license – student, NVivo subscription – AI assistant	Student subscription for NVivo 15, the chosen data analysis platform for the analysis of transcripts created through Otter.AI, including AI assistant subscription for analysing and coding transcribed interviews.	£354.00
Conference ticket	Student ticket (CIEEM member)	CIEEM 2024 Wales Conference: Peatland Restoration Student Ticket (CIEEM member)	£55.00
Total			£454.68

Statement of Contributions

Contributor Role	Role definition
Conceptualization	JHJ, LJR
Data Curation	JHJ
Formal Analysis	JHJ, SS
Funding Acquisition	JHJ, LJR
Investigation	JHJ, LJR
Methodology	JHJ, LJR, SS
Project Administration	LJR, SS
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Supervision	LJR, SS
Validation	LJR, SS
Visualisation	JHJ, LJR, SS
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Ethical approval

Emerging and developing technologies in the ecology and conservation sectors. 9115

Note: There is a newer version of the project. **Update**

Project Tree

- Emerging and developing technologies in the ecology and conservation sectors.
  - 1. Research Ethics Application Form

Action Required on Form	Status	Review Reference	Date Modified
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Risk assessment approval

Swansea University Prifysgol Abertawe

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Fieldwork Risk Assessments List

Activity/Sitevisit	Start Date	End Date	No. of Participants	Field Leader/Approver	Submitted Date	Approved Date	Risk Rating		
United Kingdom	29/02/2024	31/07/2024	1	Laura Roberts	31/01/2024	02/02/2024	Negligible/Low risk	View/Update	Print View

Dissertation Fieldwork Risk Assessment Form...

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Table of contents

List of Tables and Figures

Abbreviations

aDNA	Ancient environmental deoxyribose nucleic acid
AI	Artificial intelligence
CAD	Computer Aided Design
CIEEM	Chartered Institute of Ecology and Environmental Management
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
CV	Computer Vision
eDNA	Environmental deoxyribose nucleic acid
EO	Earth Orbiting
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IRT	Infrared thermography
LiDAR	Light detection and ranging
OAWRS	Ocean acoustic waveguide remote sensing
PCR	Polymerase Chain Reaction
ROV	Remotely Operated Vehicle
UI	User Interface
UV	Ultraviolet
VR	Virtual Reality
VTOL	Vertical take-off and landing

Acknowledgements

I would like to express my sincere gratitude to all the participants who generously shared their time, expertise, and insights for this research. I would also like to thank my supervisors, Professor Laura Roberts and Sergei Shubin, for their guidance, encouragement, and support throughout the duration of this research. Finally, I would like to acknowledge my girlfriend, Grace Crocker, for her emotional support throughout this project, without which this project would not have been possible.

1.0 Introduction

Technological development possessing merit for alleviating anthropogenic impacts to climate, ocean, and land (e.g. Regnier et al., 2013; Walling, 2006; Findell et al., 2017) is not undisputed (Piel & Wich, 2021). Conservation technology developments are necessitated by catastrophic global issues of ecosystem and biodiversity losses (e.g. Cardinale et al., 2012, Pimm et al., 2014), climate change (e.g. Berrang-Ford, Ford & Paterson, 2011; Field & Barros, 2014), and illegal wildlife trade (e.g. Phelps, Biggs & Webb, 2016; Duffy, 2016). At their core, ecology and conservation strive to understand our natural environment, the species that inhabit it, and address their challenges and threats. Technology has been and is increasingly paramount for the function of these tasks (Hahn, Bombaci & Wittemyer, 2022). Wildlife charities are emblematic of altruistic commitment for ecological benefit, but the importance of technology for completing their goals are understudied. Ecological consultancies encompass a market worth between £1-£3 billion and focus predominantly on mitigating the environmental impacts of development and construction projects (Hill & Arnold, 2012), but again academic research into understanding the role technology in facilitating their work is lacking. Consultancy and charity are comparably dynamic industries, where critical technologies often referenced include GIS, drones, data analytics, environmental DNA (eDNA), camera traps, and bat detectors (Ecological Land Services; ecologybydesign; WWF). The emergence of drones as a platform for data collection demonstrates this well, capable of being fitted with a variety of passive and active sensors to collect data dynamically in areas inaccessible to humans (Robinson et al., 2022). This in turn allows for better informed support and mitigation to increasingly critical ecological problems (Rockstrom et al., 2009). The breadth of technology used for ecological purposes is extensive, attributable to the myriads of problems and questions ecology addresses (Piel & Wich, 2021). We are reliant on technology for addressing ecological problems, as they surpass many of our human limitations, examples being light outside of the visible spectrum and sound past frequencies that we can hear. Technology can help us achieve unequivocally better results when used correctly and suitably, but capitalising on them has often been mitigated, under the guise of overreliance (Meffe, 1992; Conway, 1986). More recently, technological innovations both in novel and/or updated technologies and technological applications are becoming relatively increasingly accepted (Berger-Tal & Lahoz-Monfort, 2018). Simultaneous improvements in our understanding of ecological threats, the importance of management action, and our access to, and developments in technology facilitated their indispensability for conservation (Pimm et al., 2015; Snaddon et al., 2013).

Technologies used by the ecology and conservation sector are abundant, and range in their establishment, specificity, use cases, and novelty (Martin et al., 2016). The literature encompassing technology use for ecological industry is lacking, with seemingly more focus on the use of ecologically beneficial technologies (e.g. green technology innovation) for non-ecology specific industries(e.g. Sun, Miao & Yang, 2017; Nikolaichuk & Tsetkov, 2016; Peng et al., 2020). This project aims to fill this gap in the literature, focusing on industry uses of technologies, what is working well, what is lacking, and what are industry wants for technology in the future. The line is blurred between established and new technologies for ecology, with many established technologies being used in novel ways or in conjunction with newer technologies to address problems from different angles (e.g. drones fitted with acoustic loggers and cameras) (Lahoz-Monfort & Magrath, 2021). Though many technologies are available and routinely used by ecologists and conservationists, bespoke technologies are rarer, as they are often introduced retroactively and not created for the purpose of ecology (Hahn, Bombaci & Wittemyer, 2022). There is an urge for ecologists to move from technology consumers to be more engaged in the creation of novel technologies to better fit ecological problems (Berger-Tal & Lahoz-Monfort, 2018), and a focal point of this research is addressing and identifying the barriers to innovation in industry. Technological development in the form of software and algorithms is supported extensively by ecologists and conservation biologists (Anderson, 1992), but less engagement is seen in innovation of bespoke hardware (Berger-Tal & Lahoz-Monfort, 2018).

The following sections provide an overview of the emerging conservation technologies most referenced in literature. Additional information regarding these technologies, how they function, their benefits and limitations, and their applications is available in section 7.1 Appendix 1 of this paper.

1.1 Fixed and portable sensor devices

Sensors comprise mostly electronic devices used for the detection or data acquisition of abiotic, biotic and anthropic environmental components. The data acquired by sensors are then measured, manipulated, stored or displayed to reflect properties of environments, people and wildlife (Lahoz-Monfort & Magrath, 2021) to understand Since the inception of using sensors to record various biotic and abiotic data, no longer are ecologists limited to a handful of data types. Traditional applications of sensors are experiencing rapid technological growth attributable to advancements in nanotechnology, chemistry and optics (Porter et al., 2009). Emerging sensors or sensor applications used for ecological purposes include cameras, bioacoustics, drones/UAVs and remote sensing, and animal borne devices (biologgers) (Berger-Tal & Lahoz-Monfort, 2018).

1.1.1 Cameras

Camera traps are a staple of the ecological industry, facilitating the procurement of quality, non-invasive and user-friendly visual data. Optical cameras are used predominantly to capture photographs or videos automatically when triggering by an animal moving in frame. This technology has been used for 100+ years and possesses an abundance of literature of practice guidance (Hamel et al., 2013), reviews (Caravaggi et al., 2020), and analysis (O'Connell, Nichols & Karanth, 2011). These technologies have been critically important particularly when human presence can hinder data acquisition, such as for rare or elusive species (Cerbo & Biancardi, 2013).

Despite its long-standing use, the technology has seen particular developments in the last ~15 years which solidify it often as the preferred option in many an ecologist's technological repertoire for locating, identifying, and monitoring fauna, reflected in the tens of millions of accumulated images globally for research projects (Steenweg et al., 2017). The technology typically consists of a digital image sensor, a PIR (Passive Infrared) sensor, and auxiliary electronics (e.g. sim cards) (Lahoz-Monfort & Magrath, 2021). Camera traps are non-invasive, and when compared to traditional visual censuses produce better data (Wearn & Glover-Kapfer, 2019), particularly because many animals flee from human presence, and/or reside in areas humans have difficulty accessing (e.g. arboreal species) (Whitworth et al., 2016). Camera traps have seen many developments making them more attractive for ecological use, mostly from general developments from the photography industry, including better frame rates, faster trigger speeds, better infrared images, improved film and lenses, and higher resolution (Piel & Wich, 2021). These aspects influence cost, facilitating a trade-off between features and affordability. Camera traps have notable importance for ecological industry and are often the staple technology for consultancy and wildlife charity, where species identification, monitoring, and observation are the focal goals (Kays et al., 2020; WWF, n.d). The Bat Conservation Trust's 2023 Bat survey for Professional Ecologists: Good Practice Guidelines has recently mandated the use of cameras for bat surveys, specifically night vision aids in the form of infrared cameras (Collins, 2016). The use of infrared cameras offers improvements in the collectable data when compared to optical cameras, notably when accurately accounting for large, complex hibernation sights of bats (Krivek, 2023).

An emerging alternative to optical cameras for ecological surveying is the use of thermal imaging, although relatively uncommon presently (Still et al., 2019). Thermal imaging is the 'acquisition of thermal information from non-contact thermal imaging devices' and is recognised as a growing interest for UK ecological consultancies (Williams, 2019). Using thermal imaging provides the benefit of not relying on the availability of visible light, maintaining the detectability of animals better than the naked eye in low light environments (Williams, 2019) Infrared thermography (IRT) is an increasingly utilised method for measuring thermal stress and small-scale thermal variability in terrestrial settings, and more rarely in semi aquatic settings, i.e. intertidal zones (Lathlean & Seuront, 2014). A particularly interesting use of thermal imaging as opposed to traditional photography is for identification of protected species preceding development, including bats and birds.

1.1.2 Bioacoustics

Using acoustic sensors to record and understand sound not perceivable to human ears is an important part of ecology, as different species communicate and produce a range of sounds from infrasound (<20 Hz) to ultrasound (>20kHz). The initial establishment of sound recording technologies for bioacoustics began with tape recorders and has evolved to small sound loggers (e.g. Audiomoth) (Lahoz-Monfort &

Magrath, 2021). Sound can be a useful indication for identifying the presence of species that create noise, and variation in sound can provide insight into social composition and the behaviours of populations (Penar, Magiera & Klocek, 2020). Sonar, though initially applied for countering submarine warfare (Bjørnø, 2011), is a common aquatic application of acoustic technologies for ecology (Brown et al., 2011). Sonar multibeam echosounders, acoustic cameras, and ocean acoustic waveguide remote sensing (OAWRS) each possess properties useful for ecological applications (Munnelly et al., 2024). Sonar multibeam echosounders employ a fan of narrow acoustic beams, the slant ranges, angles and returned backscatter intensity to resolve seabed geomorphology, namely by inferring substrate and defining seabed elevation (Hughes Clarke, 2017). These multibeam echosounders are also used in conjunction with bathymetric sidescan sonar system, as the high-resolution bathymetry is important for determining the surveyed areas topography, and converting the arrival angles received into true angles of incidence (De Moustier et al., 1993). Acoustic cameras have important emerging applications, namely in the detection of small, hard to detect, moving objects, such as robots and drones (Busset et al., 2015), migrating fish populations (Martignac et al., 2014), and fish under ice (Mueller et al., 2006). These applications are important as they are non-invasive, offer higher frequencies and more sub-beams than common hydrostatic tools, enabling higher image resolution, which allows for the description of individuals based on physical properties (Martignac et al., 2014). OAWRS allows for the instantaneous and continuous imaging and subsequent monitoring of marine populations over thousands of square kilometres, allowing for the remote study of population dynamics, behaviour and movement (Jagannathan et al., 2009). Applications for acoustics include communication for ecologists surveying out at sea, detection of schooling fish and marine mammals, measuring the composition and structure of aquatic habitats, bathymetry, and movement ecology. Analysing the vocalisations of acoustically communicating animals in response to climate change has had its validity documented (Penar, Magiera & Klocek, 2020). As a burgeoning field, passive acoustic monitoring is seeing developments improve its applicability for monitoring animal behaviour, population dynamics, and responses to, and effects of environmental change (Browning et al., 2017). The proposed developments for these technologies in future is seemingly improvements in the interdisciplinary linkage between ecology, computer science, engineers, and bioinformaticians (Piel & Wich, 2021). The predominant uses of bioacoustics in ecological industry are for bat surveys (Middleton, 2020) oftentimes preceding land and building development), as a useful, non-invasiveness and cost efficiency tool for identifying and mitigating for protected species (Lopez-Baucells et al., 2021). The combined use of acoustic technology with more emergent technologies such as drones (Michez, Broset & Lejeune, 2021) and artificial intelligence (Sharma, Sato & Gautam, 2022) opens new avenues for the application of these technologies for research, but their representation in industry is lacking.

1.1.3 Drones

Drones (commonly referred to as Unmanned Aerial Vehicles) are classified as aircrafts or platforms without a pilot onboard, they can be defined as fixed-wing, multirotor, and hybrid VTOL (vertical take-off & landing). Drones are a suggested technology to fill the current void collecting data in frequent intervals on animal distribution, density, habitat and threats. These voids exist due to the high cost associated with acquiring such data (Grooten & Almond, 2018), with drones acting as a cost-effective solution while also collecting better data than traditional methods (Wich & Koh, 2018). Drones can range in their level of interaction necessary for a flight, from manual sustained control by a human, to fully autonomous calculated missions using GPS navigation (Lahoz-Monfort & Magrath, 2021), and artificial intelligence offering greater efficacy in their autonomy and accuracy (Robinson et al., 2022). Drones are a relatively emerging technology outside of their military origin, with a consumer market only emerging in the last 5-10 years at affordable prices ranging from $200-$2000 AUS from general to professional grade (Wich & Piel, 2021). The applicability of drones for ecological industry are especially beneficial when considering their improved non-invasiveness, lower disturbance, and manoeuvrability compared to traditional aircraft (Christie et al., 2016) when attempting to identify and quantify wildlife. Competition between companies in the open market facilitate the emergence of more frequent developments and capabilities, improving the range of viable options for different purposes (Crutsinger, Short & Sollenberger, 2016). Drones possess an active community, offering extensive, enthusiastic support and advice for customisability and effective practice. These technologies offer greater reach than humans or other traditional aerial surveying vehicles (i.e. sensors attached to planes) in remote, dangerous, or difficult locations (Lahoz-Monfort & Magrath, 2021). Their improved survey ability enables real-time tracking of animals and habitats, surveying large areas in three dimensions, and being compatible with a range of sensors and additive technologies (Buchelt et al., 2024; Piel & Wich, 2021). Drones are able to detect objects at increasingly fine scales, including individual animals and trees, facilitated by their compatibility with light detection and ranging (LiDAR) modules (Camarretta et al., 2020). LiDAR is classified commonly in reference to its three types of information-capturing: spatial, spectral, and temporal, (Raj et al., 2020). The spatial information can be one to three dimensional and is integral for collecting 3D maps of environments. spectral information is in reference to collecting the spectral information of a material, allowing for the classification of materials based on their reflectance. Temporal information is integral for understanding dynamic processes over time, i.e. plant growth and soil erosion, this information is collected during repeated LiDAR, whereby temporal information is collected over a specific period of time. Passive sensors, most commonly of the visible spectrum, are also increasingly used with drones (Wich & Piel, 2021). As higher resolution optical cameras are developed and used in conjunction with object recognition algorithms, drones provide a safe and manoeuvrable method for collecting high resolution data, providing increasingly detailed orthomosaics and/or density point clouds for species monitoring, and land cover classification (Cunliffe et al., 2016; Dalla Corte et al., 2020; Harrison et al., 2021). Despite the frequent association of drones as an exciting addition for ecological research, their importance for industry is lacking, and highlights a clear void in the current literature that should be explored.

1.1.4 Remote sensing

Remote sensing is the science of collecting information, importantly long-term Earth observation data remotely (Jensen, 2009). Though literally referring to studying anything remotely, ‘remote sensing’ typically refers to long distance observations (Lahoz-Monfort & Magrath, 2021). The collection of spatial information from remote sensing applications are referred to as ‘geospatial’ and denote data obtained that is associated with a location. Technologies for working with geospatial data are global navigation satellite systems (GNSS), geographical information systems (GIS), and remote sensing, which work in conjunction to collect, manipulate, calculate, analyse, visualise, and communicate geospatial data (Sinha, Kronenfeld & Brunskill, 2015). GNSS allow the scanning of environments from space at a large magnitude, and as such the data collected is often denoted as big data, and as such specialist software such as GIS are developed and used for the analysis and storage of these data. Developments to the technologies incorporated for collecting these data have allowed for better acquisition of data at a wider range of magnitudes, from local to global domains (Wang et al., 2010). The use of GIS and mobile and cloud computing, in conjunction with collaboration between academic institutions, government, and remote sensing scientists has facilitated cost effective and systematic land cover monitoring (Rose et al., 2015). The outcry for collaboration is crucial as the lack of intersection between remote sensing scientists, conservation scientists, and decision makers that manage the environment and natural resources has been reported as a barrier for the effectiveness of remote sensing (Sayn-Wittgenstein, 1992). Other barriers for using the information provided by remote sensing is cost and the need for training and transfer to newer technologies where they provide clear advantages to traditional methods (Sayn-Wittgenstein, 1992). Importantly for ecology, remote sensing has remodelled our capabilities for exploring the temporal and spatial dimensions ecological biodiversity (Cavender-Bares et al., 2022). Using observations from Earth orbiting satellites (EO) has been a long-standing and extensive field, with a suite of literature of its many applications for ecology (e.g. Aplin, 2005; Pettorelli et al., 2017; Lechner, Foody & Boyd, 2020). Important for ecology, remote sensing is used frequently to provide information to decision makers for influencing changes to policy, attitudes, and business practices for the benefit of biodiversity (Kalluri, Gilruth & Bergman, 2003; Bell et al., 2023). Compared to the traditional methods of data acquisition using satellites, the emergence of drones poses an attractive alternative method for some applications (Tang & Shao, 2015; Mohd Noor, Abdullah & Mashim, 2018) but are still in their infancy stage. As ecological industry frequently explores environments and species and their dynamics, mapping tools are a crucial resource but is lacking focused consideration in research.

1.1.5 Animal borne sensing devices

Animal borne sensing devices are denoted as devices mounted on animals that collect, store or transmit data for research, and are commonly referred to as biologgers (Rafiq et al., 2021). These technologies are an advancement of traditional methods including marking individuals and visual observations. Some examples of animal borne sensors include: miniature cameras for researching what an animal is eating and what it is interacting with (Watanabe & Takahashi, 2013), tri-axial accelerometers for measuring physical movement of when an individual opens its mouth or how many calories an animal is burning (Viviant et al., 2014; Williams et al., 2014), and magnetometers for determining the direction of view of socialising animals. Recent advancements in the miniaturisation of sensors for consumers purposes including gaming, fitness and smart phones provides excellent opportunities for ecology, as the abundance of cheap, open-source technologies makes innovation possible (Wilmers et al., 2015). Sensors being developed with customisation and a variety of measurements in mind for different consumer bases facilitate their use for a wide application of animal study, including measuring location, behaviour, caloric expenditure, and movement (Wilmers et al., 2015; Rafiq et al., 2021). These technologies are often considered as revolutionary when compared to their traditional alternatives, for instance using balloons to measure the movement of seals (Wilmers et al., 2015). These technologies are not without their limitations, as they often require augmentation to the extremities of the animals studied, often hindering their natural behaviours, reproduction, and survival, raising concerns of animal welfare (Bodey et al., 2018). Further developments to the miniaturisation of biologging sensors addresses fills a void for surveying smaller species, as the considerable size of earlier models were only applicable feasibly for larger vertebrates (Ripperger et al., 2020). The applicability of these technologies for ecological industry is not noted readily in the available literature but may have prospective uses considering the suit of data that can be gleaned from these technologies.

1.2 Field and laboratory analysis technologies

The concurrency of field and laboratory analyses have been a staple of ecology work for decades. Techniques for nutritional, faecal, hormonal, parasitological, genetics, and urine analyses are composed of multiple technologies for the acquisition of field data, and the subsequent laboratory analysis for multiple ecological purposes. In some cases, specific analysis is conducted on-site, requiring specific equipment. These technologies provide support for understanding environmental interactions and how they are likely to change with time, informed development and policy support, and recommendations for environmental impact mitigation strategies (Knott et al., 2021).

1.2.1 eDNA

eDNA is the process of documenting and surveying biodiversity by collecting and analysing DNA from environmental sources (Taberlet et al., 2018) and has shown great promise in that regard (Barnes et al., 2014). The typical methods of eDNA encompass collecting environmental samples containing DNA: soil, water, air or biological surrogates of biodiversity samples (i.e. carrion flies; Clavignac-Spencer et al., 2013) then conducting laboratory analyses amplifying DNA in polymerase chain reactions (PCR) (Taberlet et al., 2018). The emergence of eDNA improves our ability to measure information on species occurrence, distribution, habitat requirements, response to environmental impact, and abundance (Beng & Corlett, 2020; Piaggio, 2021). Though its emergence has boomed in recent years, the appreciation for understanding its benefits and limitations is lacking (Beng & Corlett, 2020). In some cases, collecting eDNA as opposed to other more traditional methods provides clear benefits for surveyors (Piaggio, 2021). eDNA methods are increasingly used for the sampling of rare and elusive species, and where non-invasiveness is of importance (Taberlet, 2018; Schwentner et al., 2021) Samples can be collected cost effectively, and easily from the environment or a single DNA carrying species (i.e. carrion flies, leeches) reducing the time taken for analysis and improving health and safety as surveyors are required in the field for less time. The efficacy of eDNA techniques is continually developing, importantly facilitating their adoption as an important citizen science resource (Biggs et al.; 2015 Larson et al., 2020), but their representation is lacking for their used by ecological industry.

1.3 Mobile applications & The Internet of Things

The increasing requirement for large data sets to be collected more frequently, and at larger scales is lent to the increasing pervasiveness of ecology-centric issues globally (Schwartz et al., 2018). These requirements are not conducive with traditional data acquisition technologies, i.e. paper and pen, but they do have their merit, they're flexible, able to change protocol any time, record any number of observations, and are extremely cost effective (McLester & Piel, 2021). Smartphones are their associated application software are widespread globally, and their use in ecology facilitate important standardisation, automation, and integration for data acquisition when compared to paper and pen (Marshall et al., 2018). Given the societal normalisation and consumer access to devices possessing a myriad of sensors, methods for information transfer and sharing, and a portable source of computing power, their frequented use in ecology deserves better exploitation (Teacher et al., 2013). Smartphones and tablets possess a range of specialisation for different practices, with dedicated GPS receivers and GNSS devices, which paired with many GIS applications available, including free open-source software and programming languages facilitate these devices for very specific or multi-purpose mapping for spatial analysis and field surveys (Nowak et al., 2020). These applications have a warranted use over traditional analogue methods in many cases, an example being Collector for ArcGIS, which can be used online or offline, and use GPS measurements or manual data insertion from a map, the latter of which important for offline surveys, for instance when in remote locales or mapping features where access is difficult/impossible (Nowak et al., 2020). There are many alternatives to Collector for ArcGIS, with varying degrees of capabilities and performance, which is important as ArcGIS is only one GIS software and has a cost, as opposed to QGIS. GIS applications are one of many applications of mobile devices for ecology and given the continuous explosion of available devices and associated software, a comprehensive overview of them all is impossible for this paper, but many properties are shared by almost all of these devices. Wi-Fi connectivity is standard among modern smartphones, and is a universally compatible standard globally, facilitating the fast and easy transfer of data to other Wi-Fi enabled devices, including compatible camera traps, drones, and other sensors (McLester & Piel, 2021). The importance of mobile applications has been cited extensively for industries, predominantly those that must adhere to ecological regulations (Brauer et al., 2016), but their importance for ecological industry is a current void in the literature.

1.4 Artificial intelligence and computer vision

Computer vision (CV) is the field of computer science focused on deriving information from bespoke algorithms for the analysis of images and video (Morris & Joppa, 2021). Computer vision offers automated image analysis improving breadth, repeatability, and duration of ecological studies (Weinstein, 2017). Within the CV sphere, machine learning (ML), the process of algorithms using data to learn how to solve problems under supervision, leverages advantages compared to traditional statistics, as they do not require unrealistic assumptions, can infer missing data, and can reduce the burden of long-term annotation (Thessen, 2016). The adoption of machine learning for ecological practice is not without its limitations and challenges, for instance deep learning, a subsection of machine learning, requires vast amounts of data, potentially requiring augmentation (Shorten & Khoshgoftaar, 2019). If we do have the necessary amounts of data, and the resources to prepare it, deep learning generally performs better than other algorithms in the accuracy of its outputs (Morris & Joppa, 2021). The potential for machine learning being used to its fullest abilities in ecology is not yet realised, as communication and collaboration is lacking between ecologists and the machine learning community about the possibilities of machine learning (Thessen, 2016). Many ecological technologies produce data in the form of images, videos, drawings and sound recordings, and as these technologies develop and upgrade, they produce exponentially more data, computer vision is becoming more and more attractive for ecological practice (Lurig et al., 2021). For ecological industry, the manual data analysis of these data vastly impedes efficient work, CV provides an automated approach that cuts down on hours of effort, but is rarely taught to ecologists (Cole et al., 2023). New approaches and benefits of using CV are mentioned in research reports extensively (e.g. McCool et al., 2018; Høye et al., 2021), but rarely for ecological industry.

Artificial intelligence in the form of large language models have been centre stage globally to mixed opinions. The potential for these models for ecology have been discussed (Agathokleous et al., 2023; Biswas, 2023). As they are in their infancy, they have yet to be tested and used extensively to provide an accurate census of their performance and come under much scrutiny for their potential to be confidently incorrect, even for simple queries (Zhu et al., 2023). These models are an alternative to training domain-specific models and allow for domain specific tasks without the need for pre-training or transfer learning but requires knowledge on how to ‘prompt’ to maximise its benefits for complex tasks (Farrell et al., 2024).

2.0 Aims and objectives

- The main focus of this research is to investigate:

  1. How and what emerging technologies are being used within the ecology and conservation sector.

  2. What is working well with them,

  3. What are the current barriers and limitations in their use,

  4. What is desired in future technological development,

  5. What are the recommendations for training and experience for early career ecologists for working with technology.

- Technologies of interest for this project encompasses those used to obtain, manage, or analyse data specific to ecology or conservational purposes. The technologies accepted under these conditions follow certain criteria so as to be deemed an 'ecological technology', as the spectrum of technologies used by ecology-centric industries and organisations may vary in regard to how they are used to facilitate work conducted for ecology. These industries encompass ecological consultancy, wildlife charities, government sectors, and research institutes.
- I aim to explore what is considered an 'emerging technology' in different ecological industries, if ecologists currently use any technology they consider as emerging or have considerations for their introduction in future.
- I aim to explore the repertoires of technologies used by the ecological industry, how they are used to address ecological challenges, what is working well with these technologies, are there currently limitations or constraints in their effective use, and opinions on where they would like to see developments to these technologies.
- I aim to establish the wants and desires of these industries, to inform what relevant changes would be most impactful for the effective use of technology by industry. Included in conjunction to opinions and statement on industry specific technology use, I aim to explore opinions on industry as a whole, in relation to technology if relevant, i.e. do they believe that industry is becoming more technological, what type of people do they see entering industry etc.

- The use of technologies by ecological industries is lacking in representation in scientific research, and information is usually only available via specific websites of the industries. The depth in exploring technology use by industries, and industry on a whole is therefor difficult, this research aims to fills these knowledge gaps in research and spur the continued exploration of ecological industry. This continued support for industry would facilitate their needs voiced more effectively and would help support those who are considering entering these fields, facilitating effective communication and dissemination of their wants and needs from the next generation of workers.

3.0 Methods

The study was conducted from September 2023-October 2024, and data collected from April-August 2024. All data and methods were conducted in the United Kingdom.

To address the research questions, a mixed methods approach was used, including interviews (offered via Zoom or Microsoft Teams) and a Questionnaire using Microsoft Forms . The initial pool of contacts for participants for the interview and/or survey was requested and accessed by reaching out to known members of the Chartered Institute of Ecology and Environmental Management (CIEEM), as well as by attending the CIEEM 2024 Wales Conference: Peatland Restoration: Approaches and Challenges in Wales (31^{st} of January 2024), the former method encompassed by known contacts of the researcher. The initial cohort of known contacts list was expanded through inquiring with other Swansea University staff of the School of Biosciences and Geography for possible research participants, as well as inquiring within the cohort for potential contacts they might know.

In addition to CIEEM members, known representatives from the environment sector of local councils, nature conservation charities, and local ecological consultancies were contacted through internet searches, social media exploration, and ecological organisation newsletter membership subscriptions (e.g. Royal Society of Biology, CIEEM). A compendium of 100+ UK wildlife charities, ecological consultancies, research institutes, and government sectors was created and tabulated, and were subsequently issued with a research participation proposition via mailing list, public contact addresses, or Contact Us website addresses. For the purpose of this study, the research institutes contacted were those involved with applied research or contract research and has a basis in industry. All contacts corresponded with are professional representatives from the ecology and conservation sector. Contact information was collected and stored securely in a password protected excel file, and the status of propositions were recorded, i.e. no response, responded and declined, responded and accepted interview/survey completion, so as to maintain current status of responses for future propositions. The exclusion criteria for this project were as follows: individuals within the sectors of interest but are a part of apprenticeship schemes or are under the age of 18 will be excluded. Individuals must have been employed within their sector for at least a year, or have fixed-term contracts within said sector, individuals in HR departments or finance, as well as retail and tourism roles, such as in cafeterias and shops are to be excluded, as interviewees must be linked to the technology used within the industry, working directly with ecology/conservation technology or have expertise in them.

Each contact had their participation requested via an email with the subject: ‘Request to participate in research on behalf of Swansea University on emerging technologies in ecology and conservation industries’, asking participation in an interview and/or survey completion. Information was provided about the conduction and goals of the research. I provided the rationale as to why I am conducting this research and how their input will be valued, defining which technologies are of interest and how I aim to use and report the results of the research. Participants were informed about what information was to be collected, and how it was to be stored. Participants were notified on how to drop out of the study and be able to withdraw information if required.

3.1 Survey

Surveys were sent out initially to contacts from the initial cohort of CIEEM members, in addition to known contacts acquired from staff members from Swansea University Faculty of Science and Engineering. Surveys were anonymized and did not collect any personal data. The aim was to have completed approximately 100 surveys. Surveys were sent to each organisation within the compendium of 100+ wildlife charities, ecological consultancies, research institutes, and government sectors. Paid advertisements were posted on Instagram from a dedicated Zoological account at £5 a day for 10 days. The survey was sent out as a public post via LinkedIn, X (formerly Twitter) and Facebook.

The survey asked 35 questions split between four sections: ‘demographics’ (questions 1-8), ‘your use of technology’ (questions 9-24), ‘perceptions and views of the conservation technology landscape’ (questions 25-30), and ‘early career/graduate skills development’ (questions 31-35). The ‘demographics’ section aimed to collect information on the organisation the participant was associated with, their role and time with the organisation, their age, an overview of the organisation’s main areas of activity, the size of the workforce, and how long the organisation has been operating. The ‘your use of technology’ section aimed to explore what technologies are currently being used and for what purpose, their experience with these technologies, the benefits and limitations of their use, and what technologies they would like to see introduced. The ‘perceptions and views of the conservation technology landscape’ section aimed to explore how people in the ecology/conservation sector view both the current state of technology, and their trajectory for the future. The ‘early career/graduate skills development’ section aimed to establish what teaching and skills are currently being implemented, and what training changes could be beneficial, for people working with technology in the conservation and ecology sectors. The full survey can be found below in section 7.2 Appendix 2.

The data obtained from the surveys was stored in security protected Excel files, held on the cloud, in a university OneDrive.

3.2 Interviews

Prior to conducing the interviews I attended an online Swansea University Geography module on research techniques in the social sciences to ensure the interviews are conducted ethically and in accordance with standard protocol.

Prior to the interviews, consent for research participation was recorded via having the participant sign a university approved consent form sent via email. All interviews were conducted on either Zoom or Teams, in accordance with the preference of the participant. Only after the signed consent form was received did the interviews commence. The consent forms were approved by the Swansea University research ethics committee [approval reference number: 3 2024 9115 8585], and the risk assessments completed preceding the project deemed the project as having a negligible risk (see the contents page for both the ethical approval and the risk assessment approval).

Prior to the interviews a literature review was conducted from primary literature, conservation technology books, and web searches to establish the relevant background of ecology and conservation technology, to better influence the type of questions asked and the themes covered. The technologies listed above in the introduction encompass the most referenced technologies at the forefront on the current literature for the fields of ecology and conservation. The influence of the literature review can be seen in sections 7.1 Appendix 1, and 7.3 Appendix 3, respectively a composite table of the technologies of interest, and the interview questions asked.

26 interviews were conducted with participants within a range of ecology and conservation industries, of which were ecological consultancies, wildlife charities, ecological government sectors, and research institutes. Each interview had standard questions which were to be asked for every participant, following a question sheet (see section 7.3 Appendix 3). Using context from answers provided by the participants, impromptu questions were asked (e.g. asking to expand on an answer), and some questions were not used if they were not appropriate (e.g. asking a question about their university experience if they had not attended). Each interview began with opening introductions and thanking them for their time and participation, providing a brief synopsis of the research, how the general flow of the interview will be, and how long the interview is likely to be. The participants were also notified that if they wanted to conclude the interview early, not answer questions, disregard statements, or opt out of the research they were permitted to do so, and all information collected would be destroyed. The interviews followed 4 main themes, 1. Current technology and use cases, 2. Challenges and barrier to using technology, 3. Benefits of technology, 4. Desired improvements to technology and the industry, and 4. Training and recommendations for early career ecologists. These themes are not mutually exclusive and were not always followed in that order. Questions were developed to avoid bias and leading answers. The topic is non-controversial and does not require personal information beyond the contact details, which were anonymised outside of personal correspondence.

Participants were first asked to describe their engagement with technology (e.g. do they work with technology personally, do they train others, or do they develop technology), and asked what technologies are currently used in their organisation (and were provided a list of examples (see section 7.1 Appendix 1)). They were then asked how these technologies were applied, for what ecological/conservation issues these technologies were used, how established these technologies were, and if/how frequently these technologies are developed upon or replaced by updated models/novel replacements. Participants were asked what technology they would consider as emerging for their industry and if they used any emerging technology currently or are considering/awaiting implementation of these technologies. I asked about views and opinions towards the performance of both established and emerging technologies, any limitations or challenges in place, if these issues currently hinder their use of the technology currently, or their implementation, and where they would like to see developments/resources put towards these technologies. Participants were asked what conservation/ecological challenges are being addressed by technology and how technology assists in addressing these issues. Participants were asked for their opinions on the current performance, experience, and knowledge of graduates and early career ecologists. They were asked where current deficits might be in regard to teaching in universities, where they would like to see improvements, what they would include/change in ecological curriculums, and where best to obtain experience outside of university, to best facilitate effective incorporation into fields similar to theirs.

Each interview was recorded on either Zoom or Microsoft Teams and transcribed with Otter.AI. Audio files of interviews were inputted into Otter.AI and a transcribed text document was created, which was then manually checked against the audio file to assure the quality of the transcription was correct. Any sensitive or personal information from the interviews were anonymised in the transcription and were stored in a password protected file. The anonymised transcripts were imported to NVivo and coded in regard to the themes mentioned above. NVivo is a software program used for analysing qualitative and mixed method research data, by assisting in the management, analysis, and visualisation of qualitative data. NVivo 15 was used for this analysis, and contained an AI assistant, this assistance was used before analysis to establish overarching similarities in interviewees, i.e. the technology mentioned, the topics covered, and the nature of their positions. The outputs from the AI assistant were not used in the creation of any quantitative data, it was used mainly as a reference for the initial formulation of code. The coding was all done manually, with branching parent codes with subdivisions of child codes, allowing for the specificity of data the deeper within a theme a subdivision was (i.e. parent code: Currently used technology, with child codes relating to each specific technology, i.e. camera traps, with subdivisions within where necessary, i.e. thermal cameras, infrared cameras etc). Codes could be words, sentences, or paragraphs that fit under a theme of interest, and denoted certain views, opinions or statements. The analysis explored how the implementation or development of technologies will benefit both the industry, and how they will affect the environment. Analysis explored propositions for how curriculums should be changed to incorporate teaching of these technologies to better qualify graduates for industry positions. Propositions will also be made for training required in industry for new hires. For changes to curriculums and industry training, feasibility was also analysed. These analyses were corresponded to similarities and differences in the interview participants, such as organisation type, years in ecological industry, technology worked with, and engagement with technology.

4.0 Results and discussion

4.1 Survey

The survey yielded a low response rate, with only 10 completed responses. Due to the limited number of responses, the data was insufficient to perform a statistically meaningful analysis or draw reliable conclusions. As a result, the survey findings were not included in the primary analysis of the research. After consulting with known two friends that work for an ecological consultancy, this limitation may be reflected by the time of distribution, as the surveys were circulated during summer when work volume is particularly high. The limitation could also be reflective of participant availability, adversity to engage with foreign research, etc. Results from the survey responses have been considered qualitatively where relevant, but caution must be exercised in interpreting any trends due to the small sample size. The results of the survey are available in section 7.5 Appendix 5.

4.2 Interviews

The distribution of participants according to industry type is shown in Table 1. Among the 26 interviewees, the majority work in ecological consultancy (n=11), with decreasing representation from wildlife charities (n=6), research institutes (n=5), and government sectors (n=4) (Figure 1). The cohort of individuals interviewed in this study presents a limitation in the robustness in industry representation that must be acknowledged when interpreting the results and engaging in further discussion. Notably, the consultancy sector is overrepresented, comprising 42% of the sample, while charities, research institutes and government sectors are represented by 23%, 19% and 15% of the total cohort respectively. This uneven distribution may limit the generalizability of findings across the ecological landscape, as the perspectives of professionals in less-represented sectors may not be fully captured, this limitation is an important opportunity for future research, increasing the robustness and validity of these findings.

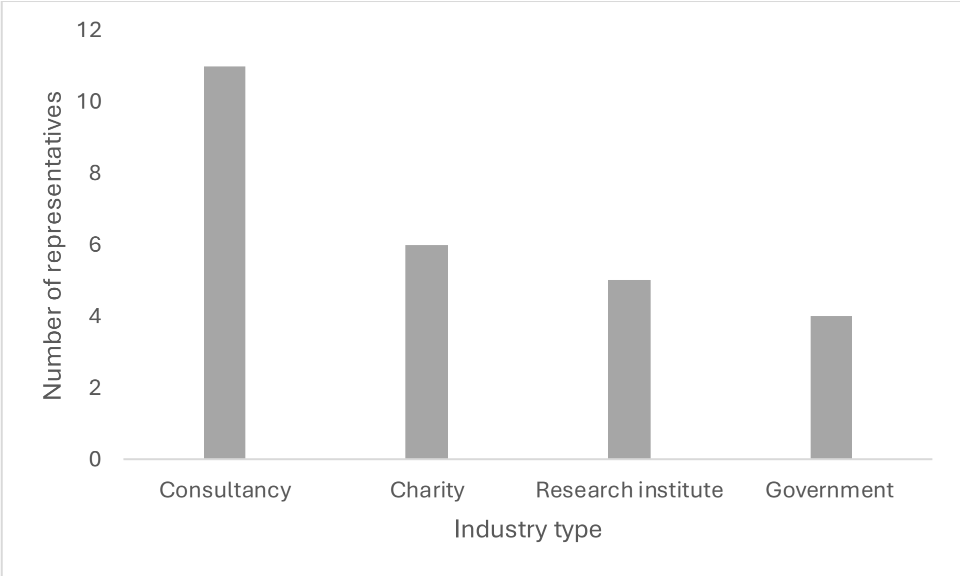

Figure 1: Number of representatives from each sector interviewed.

The below sections explore the themes discussed in the interviews, please see section 7.4 Appendix 4 for the full codebook which was used as the basis of the analysis.

4.2.1 Opinions on the current technological landscape

This section aims to analyse and discuss the opinions of industry professions of their feelings towards the current industry landscape, in regard to technology. This exploration revealed both shared and divergent perspectives on technology's role in ecology. Through analysing these sentiments, several overarching themes emerge, each illustrating the complex relationship between ecology and technology. Interestingly, the responses indicate both enthusiasm for technological advancements and reservations about their implications. Below are highlighted themes of particularly interesting or strongly communicated sentiments and their broader implications.

4.2.1.1 Accessibility as a Foundational Requirement

Accessibility emerged as the most prominent concern, with over 65% of respondents emphasizing the importance of accessible technology in ecology. This sentiment was corroborated across sectors, emphasizing the need for tools that are not only cost-effective but also user-friendly for ecologists with varying levels of technical expertise. These opinions were predominantly reflective of increasingly digital technologies becoming established over time, as software and hardware increase their capacity, customisability and functionality, the learning curve for their use becomes exacerbated. A noted example of this turmoil has been with GIS and coding software, where their capabilities are outstanding, but complicated user interfaces, and a lack of integrated explanation/tutorial limit their effectiveness for unfamiliar users. Accessibility issues encompass a myriad of things, from limiting the useability of complex software to financial constraints in technology markets lacking cost effective options, reflecting a broad consensus that accessibility for technology is foundational to further advancements in ecology. The accessibility for technology ties in with facilitating effective training, as more options for consumer grade options, and resources available for understanding new technology is critical for successful adoption. This opinion resonates with the current literature, as it implies that without accessible tools, the field's capacity for growth and innovation is significantly hindered (Hahn, Bombaci & Wittemyer, 2022). Accessibility was viewed as not only a preference but as a critical necessity for maximally beneficial technology use. It was further supported by the current literature that access to data is seen as a major limitation for conservation technology (Hahn, Bombaci & Wittemyer, 2022).

4.2.1.2 Guidelines and Policies as Both a Guide and a Barrier

The sentiment that "guidelines and policy dictate technology use" was notably strong among consultants, with over 80% in this group highlighting it as a defining factor in their technology choices. This opinion is compelling because it reveals a double-edged relationship between policy and technology. While policies ensure standards and provide a framework, they also restrict flexibility, potentially slowing down the adoption of newer, more effective tools. The general sentiment across the ecological industry suggests that while technology is moving rapidly, the regulatory environment often lags behind, creating friction in the integration process

"There's always a bit of a time lag, and there's always a, it's almost a break on innovation, yeah, and innovative practices being introduced, because if you're doing something that's a bit wild and wacky and yeah, cutting edge in terms of tech, you need to be able to defend why you have used that survey approach…"

This tension between innovation and regulation is a significant point of interest, as it suggests that policy evolution may be as essential as technological progress in advancing the ecological sector, and the relationship between technological development and their available support is critical, especially when direct support is unavailable (Hahn, Bombaci & Wittemyer, 2022). The predominant opinion of policies and guidelines is that they are behind technological development, as seen with camera traps and bioacoustics, where the technology is being developed quicker than the policies are catching up. Thermal and infrared cameras are increasingly important for ecology, but guidelines oftentimes neglect to mention them, limiting the scope of their potential establishment. The same can be seen with bioacoustics, namely for observations of birds, where the lack of their reference in bird survey guidelines conflict with professional opinions of their efficacy. These conflicts often necessitate external research to discover and begin using new technologies.

4.2.1.3 Transformation of Roles and Skill Requirements

Across sectors, there was substantial discussion regarding the rapid transformation of roles due to technological advancements. Nearly half of the respondents noted that their roles were evolving, with ecologists now expected to have more technical expertise, particularly in data analysis and digital tools, predominantly GIS and coding software. This sentiment is notable for its implications on workforce development; as technology continues to shape the industry, ecologists will need continuous upskilling and support to remain relevant, especially for long-established workers that may be more resistant to technologies viewed as complex and frustrating, commonly digital alternatives to traditional methods, i.e. thermal cameras replacing eyewitness observations and data logging apps and programmes replacing pen and paper (Faraca & Mustell, 2024). Traditional field skills, i.e. paper and pen, are increasingly complemented (and sometimes replaced) by technology, but their successful succession is necessitated by improved support. This evolving skillset requirement signals a need for institutions and organizations to invest in training programs to equip current and future ecologists with the skills to navigate an increasingly shifting technological landscape. This sentiment is relatively unseen in the current literature but could be an interesting avenue to explore given its increasing relevance.

4.2.1.4 Demand for Bespoke and Ecologically Considered Technologies

A recurring sentiment was the desire for bespoke technologies tailored specifically to ecological needs. Many respondents observed that tools adapted for other purposes often lack the functionalities crucial for ecological work, while possessing many functionalities not important for ecology, leading to inefficiencies in their use and increased cost. A highly referenced example of this was seen in GIS and coding software, where the increasing number of additive tools and methods for other disciplines increase the visual noise of the interface and complicate the flow of specific analyses. This points to a gap in the technology market that, if filled, could greatly enhance productivity and accuracy in the field, while also facilitating developer competition, in turn providing a more cost effective and expansive market. The call for bespoke solutions reflects an industry-wide recognition that ecology has unique requirements not met by generic tools. This demand for tailored solutions is a potential growth area for technology developers and an interesting pathway for ecologists to collaborate with technologists to create more specialized tools. Considering its voiced importance, further research should aim to better explore the demand from industries for better consideration in technological development.

4.2.1.5 Balancing Enthusiasm for Innovation with Caution

Interestingly, the ecological industry is simultaneously optimistic and cautious about technology. Many respondents noted an enthusiasm for innovation, with technology being viewed as a catalyst for advancements for conservation goals. However, this optimism is tempered by concerns about "overhyped technology" and the overwhelming number of options becoming available. Many ecologists have seen technologies branded as revolutionary not live up to their potential, where instead the implementation of new technologies should be focused on longer term results leaded with continued support. The excitement for revolutionary technology has been seen with eDNA, where its implementation was believed to be too early, and the established counterpart, microscopes, were shunted while eDNA was still in its infancy. While industry is frequently interested and excited for technological advancements, professionals are also wary of the investment and risk of adopting tools that might not deliver as advertised.

4.2.1.6 Shared Challenges Across Sectors

While there are notable differences in how technology affects different sectors, several interviewed representatives shared challenges, especially around collaboration and data integration. For instance, respondents noted that “technology is often made for non-ecology purposes” and that it’s “difficult to collaborate due to competition between industries.” These opinions indicate a broader systemic issue where the lack of ecological-specific technology and inter-sectoral competition hinder collaborative efforts, with industries being prone to becoming siloed. The need for standardization and collaboration across different ecological sectors is desired, suggesting that an industry-wide approach could be beneficial for improving the shared knowledge of potential technologies for expanded integration. By aligning technological efforts and fostering collaborative networks, the ecological industry could collectively advance conservation issues in mutually beneficial connectivity.

4.2.1.7 Technology as Both an Opportunity and a Threat to Traditional Roles

The sentiment that “technology is replacing surveyors” alongside a more optimistic view that “ecologist roles are changing rapidly” illustrates a complex relationship with technology’s impact on traditional roles. Though referenced extensively as a worry of industry (Faraca & Mustell, 2024; Vorobeva et al., 2022), the literature surrounding the impacts for ecological industry are lacking. Some participants see technology as enhancing their ability to work with data, i.e. AI tools and automated data processing, and handle labour-intensive and potentially dangerous tasks, i.e. autonomous vehicles and remote data acquisition. These developments are seen as adding value to ecological work, improving working conditions, and facilitating more time to focus on conservation goals. Others, however, express concerns about the potential of technology to replace core ecologist functions and undermine the importance of ecologists, referenced commonly as data processing tools doing the work instead of manual analysis by a person. This supposition is conflicted by others view of the same scenario being that the tedious busywork is done automatically, freeing up that ecologist to work on other aspects of their work. Addressing these feelings is paramount and understanding how to integrate technology in a way that mitigated frustration and opposition while complementing rather than displacing the role of the ecologist is crucial. Ecological expertise is critical, and many believe not replaceable by technology fully, and addressing the worries of those feeling threatened in industry is important. Technological threats mainly encompass threats to education in the current literature, with an important void for industry that should be considered.

4.2.2 Currently used technologies and use cases

Please see Table 1 below for an extensive overview of currently used technologies for each industry type considered, as well as their associated total across all industry types. Across all industry types considered, 26 distinct technologies/groups of technologies were identified. A large discrepancy was exhibited between the top 11 most referenced technologies and the remaining 15, with a large drop-off in reported uses between the 7th most popular and 8th most popular technology. AI was identified the most with 20 individuals (76.9%) across every industry considered, GIS software was referenced by 17 (65.4% of individuals), mobile phones and tablets by 16 (61.5%), bioacoustics and camera traps both by 15 (57.7%), drones by 13 (50%), coding software by 11 (42.3%), GPS and biologgers by 8 (30.8%), eDNA by 7 (26.9%), and EO satellite data and Internet of Things by 6 each (23.1%). Every other technology was referenced by 1-2 people. Interestingly for the most referenced technologies significant overlap is exhibited between industries, without any significant outliers that were referenced frequently.

In addition to the technologies already discussed above in this research paper, a number of not before mentioned technologies were discussed, and warrant context, including advanced robotics, automatic water level readers, gas analysers, remotely operated vehicles (ROVs), sniffer dogs, 3D printing, digital twins, ARCboats, Clustered Regularly-Interspaced Short Palindromic Repeats (CRISPR), polymerase chain reaction (PCR), virtual reality (VR), and X-ray.

Advanced robotics is classified as the field of robotics related to developing highly sophisticated robotic systems, commonly employing AI to create robots that can act autonomously, perceiving and reasoning in complex situations (Soori, Arezoo & Dastres, 2023). Advanced robotics using AI are often noted alongside digital twins, a virtual model/digital counterpart of a physical object, process, or system (Huang et al., 2021). Digital twins is a revolutionary method of understanding systems and processes and has the potential to influence the standard of digital transformation in ecology (Koning et al., 2023). Where complex, dynamic processes exist in ecology, the requirement for improved investigation is necessary, with frameworks being created for biodiversity and conservation management (Sun & Xu, 2024).

Automatic water level readers are electronic devices for measuring water levels in various water systems, including lakes, rivers, and reservoirs, encompassing a power source, sensors to detect the water level, and a datalogger to record, store, and sometimes transmit readings remotely. The benefits of automatic water level reading is less human effort is necessary in manual readings with measuring sticks, as readings can be collected remotely so that environments can be monitored long term easily.

Gas analysers are used to measure the concentration of gases in the atmosphere, soil, or water to understand environmental impacts and processes.

ROVs are a globally used technology for the monitoring of subsea infrastructure integrity and environmental spatial analysis (McLean et al., 2018). A predominant use of ROVs for ecology is the analysis of oceanic environments, with their performance supported by their capacity as highly customisable platform for sensors and accessory technologies, including cameras and lasers (Vigo et al., 2023).

Sniffer dogs are a longstanding method used by industry for scent detection, a common example being for explosive detection (Gazit & Terkel, 2003) and have their important uses in ecology for locating species. Species location and subsequent protection has been documented in a variety of species, including amphibians (Matthew, 2016), beavers (Rosell et al., 2019), and koalas (Cristescu, Miller & Frere, 2020). Their uses for ecology operate on the understanding that manual human observations for locating animals can be lacking, and having an improved olfactory companion can improve the detection rate and the subsequent validity of data collected.

3D printing offers an opportunity for three-dimensional equipment production with a great level of freedom in their design, where the 3D digital models used for the physical design can be shared easily, improving the replicability and customisability of equipment used within the scientific community (Walker & Humphries, 2019).

ARCboats refer to remotely controlled, highly manoeuvrable boats that are operated from the periphery of water bodies, eliminating the need for people to venture out onto the water, accelerating data collection (Watchorn et al., 2021). Their small size and high manoeuvrability enable them to get close to objects of interest and venture where larger vessels are unable to, enabling safe data acquisition of bathymetry and morphology of aquatic systems.

CRISPR is a gene editing technology that uses a naturally occurring bacterial defence system to precisely target and manipulate DNA. CRISPR has high clinical potential for treating human disease and editing the human genome by editing DNA to understand the mechanisms of genetic diseases (Lino et al., 2018). PCR can be use alongside CRISPR and is a laboratory technique used to amplify a specific segment of DNA. PCR is one of the most valuable techniques for biosciences, forensic sciences, and diagnostics (Zhu et al., 2020).

Virtual reality is the computer-generated simulation of a 3D image or environment which is able to be interacted with specialist equipment such as a mounted helmet with a screen inside, or sensor laden gloves. VR for ecology generally encompass increasing understanding of complex natural environments, influencing empathy and personification with nature, and promoting behaviour changes beneficial for nature (Vercelloni et al., 2021).

X-ray refers to an electromagnetic wave of high energy and very short wavelength able to pass through many materials opaque to light. Developments to X-ray computed tomography offer an affordable, simple method of understanding 3D anatomy of species morphology and physiology *in vivo* and *ex vivo* (Gutiérrez et al., 2018).

Table 1: Currently used technologies by interviewees in regard to industry type.

Technology	Consultancy % (n=11)	Charity % (n=6)	Government % (n=4)	Research institute % (n=5)	Total % (n=26)
AI	63.6	100	75	80	76.9
GIS software	81.8	83.3	50	20	65.4
Mobile phones and tablets	72.7	50	75	40	61.5
Bioacoustics	81.8	50	50	20	57.7
Camera traps	90.9	66.7	25	0	57.7
Drones	18.2	83.3	100	40	50
Coding software	45.5	50	25	40	42.3
GPS and biologgers	9.1	83.3	25	20	30.8
eDNA	18.2	50	50	0	26.9
EO satellite imagery	9.1	33.3	50	20	23.1
Internet of Things	9.1	16.7	25	60	23.1
Advanced robotics	0	16.7	25	0	7.7
Animal traps	9.1	0	25	0	7.7
Automatic water level readers	0	0	50	0	7.7
Gas analysers	0	16.7	25	0	7.7
ROVs	0	16.7	0	20	7.7
Sniffer dogs	9.1	0	25	0	7.7
3D printing	9.1	0	0	20	7.7
Digital twins	0	0	25	20	7.7
ARCboats	0	0	25	0	3.8
CRISPR	0	0	0	20	3.8
PCR	0	0	0	20	3.8
VR	0	0	0	20	3.8
X Ray	0	0	0	20	3.8

Further analysis of technology usage across ecological consultancy, charity, government, and research sectors revealed both shared technological applications and distinct applications suited to the operational needs of each industry. Ecological consultancy displayed the highest proportion of use for camera traps, with 10 of the 11 (90.9%) total participants employing these for species monitoring and identification. Within this cohort, a nuanced distribution of camera types is evident: 33.3% of consultancy participants utilized endoscopes, with their use exclusive to bat surveys, while 80% employed infrared cameras and 60% used thermal cameras, both covering a broader range of species identification applications. The use of endoscopes is an established technology and is not seen as emerging. One individual reported that they had designed and used a custom optical camera tailored for specific surveying needs, incorporating Raspberry Pi, CAD software and 3D printing in its design for effective use in bat surveys. This technological adaptation was acknowledged celebrated for its innovation, and its design is looking to be rolled out:

"So I had, had had a sort of thought that I could just, I'll make an alternate, alternative trail camera myself, on the basis that, well, we using bat detectors, and the way some of the bat detectors work, and the bats in particular, is that they record continually into their internal memory. And so when it records a bat, it saves a previous few seconds of audio information and then the next few seconds after that. So you don't have, you don't cut off, or you don't cut off the start of the call, you record the full thing. So I thought, Well, why can't we do that with video? So I made a camera that does that… I made the case in a sort of CAD software, and then sent it off to a 3d printer, and they, they printed it, and then I fitted all the bits and bobs inside of it, yeah, and then yeah, and won an award for innovation"

This development is particularly important as the push for innovation is large in ecology, and encouragement towards increasing innovation is crucial, especially when innovation fills specific niches for the betterment of conservation work (Hahn, Bombaci & Wittemyer, 2022).

Bioacoustic technologies were frequently cited across all sectors and varied in their application. In consultancies, bioacoustic monitoring was predominantly used for species identification, encompassing 33.3% of cases, particularly in bat surveys, with associated programmes for generating sonograms, the referenced example being

Kaleidoscope, for species identification. Charity sector participants expanded bioacoustic applications further, encompassing both bat surveys and soil echoacoustics to monitor in-soil biodiversity. Government participants also identified bioacoustics for bat and bird monitoring in 50% of cases, marking a notable alignment with the charity sector's monitoring priorities but differing in use case emphasis. Bioacoustic technologies were denoted as being longstanding established technologies but are considered emerging when considering their development. An example of emerging bioacoustic technology is passive acoustic monitoring, whereby developments to sensor hardware, machine learning capabilities, and automated species identification are being newly incorporated (Gibb, Glover-Fapfer & Jones, 2018). Furthermore, GIS software was a technology foundational for habitat mapping across all sectors, serving conservation concerns surrounding habitat classification, distribution monitoring, and assessing disturbance resilience in consultancy and government contexts. Charities additionally used GIS to support public and policy communication, while research participants emphasized GIS for habitat resilience assessments, evidencing its broad applicability in ecological spatial analysis. GIS software are commonly seen as established technologies but are often denoted as having emerging applications as the software itself develops and updates, complementary data collection technology are implemented, i.e. drones (Quamar et al., 2023), and open-source databases are expanded (Wegmann, Leutner & Dechm, 2016).

AI technologies were prevalent across all sectors, with varied but often complementary uses. In government, the emergence of large language models and deep learning facilitate streamlined report writing, dataset refinement, and application of carbon metrics to ecological datasets. 75% (3 of 4) of participants highlighted AI's especially useful role in expediting traditionally time-consuming or repetitive tasks. Similarly, multiple consultancy participants newly implemented large language models for automation and efficiency, such as debugging code, document proofing, and data summarization, aligning with research institutions where 80% (4 of 5) used large language models for similar time-intensive or standardised tasks. An interesting emerging use case for AI mentioned was for identifying illegal animal trades by searching for key terms and words associated with poachers online. This use has been documented previously, with social media deep dives using AI to identify illegality

(Minin et al., 2018). Charities, however, showcased a higher emergent adoption of machine learning (83.3%) to classify habitats, identify species from EO satellite and camera trap data, and for species and population dynamics studies through footprint identification. The adaptability of AI across ecological industries, with large language models and machine learning commonly applied to streamline data processing and species monitoring in complex ecological contexts.

Drones represented another frequently used but newly implemented technology with applications that were unique to each sector. Government and charity participants reported relatively high proportional use of drones, with 100% and 83.3% of participants respectively, using drones for habitat assessment, while research institutions and consultancies used drones less frequently (18.2% and 40% respectively). Of the 4 government representatives using drones, 2 reported the emergent concurrent use of drones with LiDAR sensors for 3D mapping, specifically for flood risk management and creating more detailed habitat models. This application has had its efficacy supported by recent literature (Trepekli et al., 2022; Govedarica et al., 2018) and is generally accepted as an important emerging technological application. By contrast, representatives from charities applied drones for more diverse applications, such as using ground-penetrating radar for soil mapping, locating bird nests, and identifying visually tagged species using UV paint, demonstrating and supporting the versatility of drones for varied emerging conservation efforts (Robinson et al., 2022). For research institutions, drones were utilized primarily with multispectral imaging sensors for high-resolution species distribution mapping, supporting external ecological research where resolution, specificity and accessibility is paramount. The variability in drone use cases within each sector reveal a high degree of adaptability and customisability present in drone aided work, with each industry tailoring drone technology to its ecological and conservation priorities, in part facilitated by their compatibility with varied sensors, and their potential for accessibility for spatial positioning in three dimensions (Surasinghe, Singh & Frazier, 2025).

Coding software, including R, Python, and CAD, though not considered emerging technologies, demonstrated versatile emerging applications across sectors. Charities primarily employed coding software to analyse datasets obtained from other technologies, an example being understanding threats to marine protected areas and fisheries management obtained through emerging technologies, including ARCboat and ROV applications. Government participants utilized R and Python to model river invertebrate populations and freshwater ecological data. In research settings, the emergence of new, bespoke models in Python and R facilitated complex spatial data analysis, such as using AI and GIS software concurrently to generate orthomosaics for kelp distribution mapping. The consultancy sector displayed predominant use of R and CAD, and to a lesser extent, Python, for general analytics of large datasets. These methods are often necessitated by the increasingly large data acquired by emerging methods of data acquisition, examples being the continual autonomous recording of thermal cameras and bioacoustics. These results indicate a trend toward the necessity of advanced data handling in ecological analysis (Farley et al., 2018), with research institutions in particular pushing the boundaries of spatial data application through software-aided remote sensing and the creation of bespoke coding models.

Within consultancy, 18.2% of participants identified eDNA as an emerging technology for species monitoring, specifically focusing on protected species like great crested newts, where eDNA analyses provide more accurate evidence-based mitigation strategies for conserving biodiversity and protected species within development projects. Government participants applied eDNA for invasive species detection, ecological health monitoring, and disease detection, while the charity sector use cases included bat hibernation studies, predator-prey relationship assessments, and community-driven biodiversity sampling. These examples demonstrate eDNA as an accurate, versatile asset in conservation biology and biodiversity monitoring, particularly within the context of identifying and mitigating for environmental threats non-invasively (Schwentner et al., 2021). Laboratory technologies were predominantly associated with research institutions, with one participant citing advanced emerging methods such as CRISPR for genetic manipulation, PCR for disease diagnostics, and VR and 3D printing for the visualisation of complex invertebrate morphology for educational purposes. The use of VR and 3D printing for education is increasingly interesting, as they provide a tactile and interactive route for improving public knowledge on conservation technologies and their use cases (Vercelloni et al., 2021).

While camera traps, bioacoustics, GIS, drones, AI, coding software, and eDNA were the most frequently referenced emerging technologies across industries, their specific applications varied. Government and consultancy primarily encompassed the emergent concurrent use of GIS and drones for detailed spatial and species data, while charities integrated a multi-technology approach to foster public engagement through recently broadening citizen science approaches. Research institutions demonstrated a high degree of variability in the technologies used and their applications, particularly in remote sensing, spatial data modelling, and laboratory technologies for genomic analysis. These technologies and their importance are referenced extensively in the current literature (e.g., Lahoz-Monfort & Magrath, 2021; Berger-Tal & Lahoz-Monfort, 2018) but a distinct lack of industry focus is apparent for ecology which should be considered given the importance of these industries for ecological and conservational impact.

4.2.3 Prospects for future technology use

Table 2 illustrates technologies considered for possible future implementation within the ecological sector. These technologies were almost exclusively seen as emerging, even if seen as established by similar industries and companies. Artificial intelligence (AI) emerged as the most frequently mentioned technology, with 42.3% of respondents recognizing its potential. Consultancy, in particular, showed a strong interest (72.7%). The application of AI by those not already using it particularly identified the emergence of large language models as attractive for the automation of standard, time consuming processes such as report writing, but have important considerations for their use:

“But in terms of AI and things, we haven't really looked into potential uses within ecology, there's probably something that we, you know, we'll be looking at in the future, particularly with sort of automating some processes, making reporting more efficient and things like that. I imagine that AI would have a use there, but it's quite a sort of sticky topic, isn't it, at the moment, and we don't want to sort of de skill our workforce by sort of over reliance on those sorts of technologies”

Other prospective emerging applications of AI were for using object detection for the automatic identification of species from camera trap data, identified by consultancy and charity, including motion detection software (11.5%) specifically for bat surveys and identification by footprint analysis. Classifying habitat from aerial imagery was further identified by consultancy as beneficial for facilitating more efficient ground truthing for larger areas. A representative from a research institution identified the incorporation of AI for incorporating centres of excellence for a recently undertaken bespoke AI project for assessing and managing environmental health.

Drones were identified by 23.1% of respondents, particularly within consultancy (36.4%), as a valuable new tool for environmental monitoring, mapping, and surveying hard-to-reach areas. This points to the utility of drones in gathering high-resolution data with minimal disturbance to ecosystems, a benefit that has been highlighted in recent ecological studies (Robinson et al., 2022; Gallego & Sarasola, 2021). The main prospects identified were for researching the possible expansion of drone applications for other use cases, where drones are already used already. Others reported considering introducing drones for projects and surveys that use satellite imagery to expand and maximise robustness.

Table 2: Prospective technologies for future implementation into ecological industry.

Future implementation	Consultancy % (n=11)	Charity % (n=6)	Government % (n=4)	Research institute % (n=5)	Total % (n=26)
AI	72.7	33.3	25	0	42.3
Drones	36.4	16.7	25	0	23.1
eDNA	9.1	16.7	25	20	15.4
Biologgers	27.3	0	0	0	11.5
Motion detection software	27.3	0	0	0	11.5
3D printing	0	0	25	20	7.7
Advanced robotics for arboriculture	0	16.7	25	0	7.7
Bioacoustics	0	16.7	0	20	7.7
Citizen science	0	16.7	25	0	7.7
aDNA	0	0	0	20	3.8
Alternative power fishing boats	0	16.7	0	0	3.8
Bespoke precision fishing and trawling technology	0	16.7	0	0	3.8
Infrared cameras	0	16.7	0	0	3.8
Portable analysers for environmental surveys	0	0	25	0	3.8
Ultrasonic water level sensors	0	0	25	0	3.8
Further refining AI models	0	0	25	0	3.8
Incorporating centres of excellence for ecology	0	0	0	20	3.8
Programming to create models to streamline analysis	0	0	25	0	3.8
Researching methods of handling big data	0	16.7	0	0	3.8
Using quantum computing for DNA analysis	0	0	0	20	3.8

eDNA was cited as potentially useful by 15.4% of participants. Although its prospective adoption was relatively low across sectors, references made by consultancy identified its prospective use as a more emergent, science backed method for biodiversity estimation and monitoring threatened species. Their potential adoption for research suggested eDNA as possessing potential for more accurate categorisation of species but requires their improved understanding on the factors that improve its categorisation efficacy (Mauvisseau et al., 2019). Charity identified eDNA as being an attractive emergent addition for citizen science research if developments are made in the portability and expansion capabilities of easy to use, portable eDNA kits. Ancient DNA (aDNA) was referenced as a new attractive prospect for future implementation for supporting the databasing of species in conjunction with the established CRISPR for preventative and treatment studies for conservation. The importance of eDNA has been cited extensively in regard to citizen science, but a distinct industry focus is apparent in its application (Larson et al., 2020).

The potential incorporation of biologgers was identified specifically within consultancy. The technology itself was seen as emerging due to recent hardware developments consolidating efficacy for smaller species. Their prospective emergent use cases included mitigating collateral deaths of bats from human developments by collaborating with windfarm developers for establishing curtailment regimes (Sassi et al., 2025). Their incorporation for bat surveys was also identified specifically through using emerging triangulation receivers for obtaining more accurate and frequent location of bat roosts and habitat use for mitigation strategies.

Other technologies, including 3D printing, bioacoustics, and advanced robotics for arboriculture, were each mentioned by 2 (7.7%) respondents. Some of these technologies were referenced as more niche use cases, including emerging applications of 3D printing for producing custom animal traps better reflecting natural environments, and accessing inaccessible physical structures for arboriculture surveys. Emergent uses for established bioacoustics were instead mentioned in regard to their concurrent use with remote sensing data and AI models for biodiversity and species composition analysis for research purposes.

4.2.4 Important benefits of emerging technologies

Table 3 indicates a variety of benefits associated with emerging technologies across different ecological sectors. The most universally acknowledged benefit is the improvement in efficiency and reduction of time consumption, cited by 96.2% of participants overall and reaching 100% across all sectors except consultancy, where it was still high at 90.9%. This benefit was reported for the majority of emerging technologies considered in this project, of those AI, eDNA, drones, night vision aids, and mobile devices and apps were most frequently cited. AI was referenced the most, cited by 16 of the 26 interviewees, encompassing large language models, machines learning and object detection as optimising standard processes and data analysis, freeing up ecologists from time consuming analytics to allocate their time more effectively for other tasks (Daugherty & Wilson, 2018). Efficiency for field technologies, including sensors, eDNA and mobile apps were associated most with facilitating more frequent data acquisition, namely through their ease of use. Many of the technologies considered as efficient were identified as such through their capabilities to replace surveyors. Camera traps, static recorders, and ROVs facilitate autonomous data acquisition, and can obtain data over larger time frames while replacing surveyors. Improvements to efficiency are consistent with findings from similar research and is cited as an important addition to effective conservation research (Arts, Van der Wal & Adams, 2015).

Cost benefits were also recognized broadly, with 88.5% of respondents highlighting this as a desirable aspect of their technologies. Charity organizations and consultancy sectors rated this benefit the highest (100% and 90.9%, respectively), underscoring the economic appeal of emerging technologies, especially in sectors where budget constraints are common, namely smaller teams (Boyabatlı et al., 2016). Customizability and applicability were similarly highly valued, particularly among charities, government, and research institutes (100% each), reflecting a sector-wide appreciation for adaptable technologies that are able to be manipulated for specific use cases. Cost benefit as an associated benefit of conservation practice is often subject to compartmentalisation due to research specificity (e.g., Atampugre, 2014; Zhou et al., 2009) and focus is rarely placed on the technologies, which could be an important avenue to explore more expansively.

Table 3: Benefits referenced in regarding to emerging technologies for each industry type.

Benefit	Consultancy % (n=11)	Charity % (n=6)	Government % (n=4)	Research institute % (n=5)	Total % (n-26)
Efficiency and time consumption improvements	90.9	100	100	100	96.2
Cost benefit	90.9	100	75	80	88.5
Customisability and applicability in technology applications	72.7	100	100	80	84.6
Improved conservation and biodiversity promotion and dissemination	54.5	100	75	100	76.9
Improved precision and resolution	81.8	50	75	60	69.2
Accessibility	54.5	100	75	40	65.4
Effective for ensuring correct practice	90.9	50	50	40	65.4
Health and safety	90.9	83.3	25	0	61.5
Improved user friendliness and effective usability	63.6	83.3	25	60	61.5
Career opportunity and perception of industry	27.3	50	50	60	42.3
Larger data and data types available	36.4	50	25	60	42.3
Provide more evidence backed methods	54.5	33.3	50	20	42.3
Technology replacing surveyors	54.5	50	25	20	42.3
Facilitating skills development	36.4	33.3	25	60	38.5
Exploring emerging fields and applications	18.2	50	25	40	30.8
Multiple technologies are effective when used together	27.3	16.7	0	40	23.1
Portability and miniaturisation of sensors	27.3	16.7	25	0	19.2
Reduces complexity of analysing overwhelming data	27.3	16.7	0	20	19.2
Ruggedness and robustness	18.2	33.3	0	0	15.4
New biodiversity metrics provide more survey autonomy	18.2	16.7	0	0	11.5
Technology it designed for ecological purposes	27.3	0	0	0	11.5

Improvement in conservation and biodiversity dissemination was another prominent benefit, especially noted by charities and research institutions (both 100%). This emphasis on conservation outcomes highlights how technology is instrumental in enhancing biodiversity-related initiatives, allowing for effective communication and implementation of conservation strategies. These benefits were commonly identified in GIS software, as they provide an effective interface for disseminating data for decision makers to ensure action plans and strategies proposed are understood. The importance of conservation education is highly cited (Jacobson, McDuff & Monroe, 2015; Wickens, King & Napolitano, 2022), but the importance of technology for education is a current void in the literature and should be considered in future.

In terms of operational benefits, technologies were valued for their increased precision and resolution (69.2% overall), with consultancy and government sectors especially referencing enhanced data accuracy. These improvements were referenced in regard to multiple technologies, including AI models, cameras, drone mounted sensors, and microscopes. Accuracy was most valued for ensuring correct species identification and animal counts, which is a critical aspect of surveys designed for mitigating threats to and protecting animals and habitats. Accessibility also emerged as a significant advantage, particularly in charity and government sectors (100% and 75%, respectively). Accessibility was referenced most regarding consumer level options, which is especially important for smaller teams with less resources. Consumer level, off the shelf alternatives for cost effective drones and cameras were valued highly, as competition in their development facilitates more options for consumers, which in turn improve the choice for options for specific use cases (Lanzara & Morner, 2003). Career opportunities (42.3%) and skills development (38.5%) were both largely consolidated benefits which both stemmed technology facilitating variability in career options. There are more options for feasible specialisation into emerging technologies, namely AI, GIS, and analytical software which make ecological industries more accessible. These technologies facilitate accessibility for those who might be averse to working in the field, inviting options for remote work, especially important for people with disabilities and health conditions (Bruyere, Erickson & VanLooy, 2006). The shift in perception of ecology work being considered fully practical and field based is an important step for accessibility and should be researched in further detail outside of this paper.

Other benefits, such as improvements in health and safety (61.5%) and user-friendliness (61.5%), these benefits are often referenced in conjunction with accessibility. These benefits demonstrate that technology not only contributes to better data quality but also positively impacts the working conditions and usability for practitioners. These aspects are essential for ensuring that technology adoption is sustainable and user-centred:

"You know, some of the less, less good industries, for example, have taken advantage of their employees, or have taken advantage of freelance ecologists, getting them to do too many surveys, and potentially the thought of having to do that work is a barrier for some people getting into the sector. You know, as you know, think about a career changer with kids, for example, and they're told that you have to do dawn and dusk survey work or you won't get a job as an ecologist, so, so there's a really good opportunity there where, where we can use monitoring devices to improve terms and conditions for people who are working in ecology"

Improved health and safety were identified largely in technologies that are able to replace surveyors, and collect data autonomously or remotely, including drones, cameras, sniffer dogs, and ROVS. These technologies allow for data collection in conditions unfavourable and potentially dangerous for ecologists, including in adverse weather conditions, aquatic systems, and when data is collected high above ground. These benefits were also referenced as being concurrently beneficial with improved ruggedness and robustness of field sensors (19.2%). User friendliness was identified as an important property especially in eDNA methods and data logging applications, as it ensures technologies are used correctly and learned easily, and the outcomes of the technologies are more robust and to a higher standard. ROVs were also referenced, along with drones, cameras, biologgers and acoustics as being beneficial due to the miniaturisation and portability of sensors (19.2%), further facilitating their ease of use, power consumption, and transportability of multiple sensors and sensor types.

4.2.5 Challenges and barriers to using technology

4.2.5.1 Barriers to implementing emerging technology

A significant barrier to introducing emerging technologies to industry was identified as reluctance to introduction and innovation from others in industry, which was identified by 13 of the total 26 interviewees (50%) (Table 4). This barrier was identified in every industry type considered, with the largest proportion of interviewees from consultancy and research institutions (63.6% and 60% respectively), closely followed by government (50%), and only by one participant from charity (16.7%). An important facet of this barrier was linked to wanting to avoid an overreliance on AI, this belief was shared by 4 individuals from consultancy and 1 from a research institute, where they consolidated known feeling that the introduction of automated processes may reduce the quality of output when compared to manual analysis, i.e. identifying species of interest from camera trap footage. Representatives from consultancy, charity, and research institutes identified colleagues in their industry worrying that introducing AI would take work away from ecologists and deskill workforces, namely in field sensors replacing surveyors, and AI for data analysis (Faraca & Mustell, 2024). Another barrier for field technologies taking the place of surveyors in the field is concern for expensive specialist equipment to be damaged, stolen or vandalised. In most cases where representatives are paraphrasing for others in industry, proposed solutions include demonstrating the benefits of working with emerging technologies through improved training and support to alleviate frustration and demonstrate the importance of ecologists as critical resources that aren’t likely to be replaced (Helpman & Rangel, 1999; Barna, Hrytsak & Henseruk, 2020). Another barrier to introducing AI, specifically large language models for consultancies, was negative feedback from trialling, which was referenced by 36.36% of representatives from consultancy. Negativity was identified in response to issues with accuracy when using these models for automating standard procedures, including report writing.

Table 4: Barriers to introducing emerging technologies to industry.

Barrier	Consultancy % (n=11)	Charity % (n=6)	Government % (n=4)	Research institute % (n=5)	Total % (n=26)
Reluctance to introduction and innovation	63.6	16.7	50	60	50.0
Project proposal processes and policy	54.5	50	50	20	46.2
Cost benefit	9.1	50	50	40	30.8
Time investment of introducing new technologies	27.3	33.3	25	20	26.9
The changing landscape is overwhelming	27.3	16.7	25	20	23.1
Negative feedback from trials	36.4	0	0	0	15.4
Accessibility of specialist tech	18.2	0	0	0	7.7
Current methods are adequate	0	16.7	25	0	7.7
Lack of a stable enough platform for effective IoT	0	0	0	40	7.7
Potential privacy concerns	0	33.3	0	0	7.7
Protocol for handling large data	0	33.3	0	0	7.7
Fear of expensive tech being stolen if left unattended	9.1	0	0	0	3.8
Fire risks of alternative power fishing boats	0	16.7	0	0	3.8

The next most referenced barrier to introduction was attributed to the project proposal process and policy (46.2% of interviewees), the proportion of interviewees referencing this barrier from consultancy, charity, and government were similar (54.5%, 50% and 50% respectively), with only one representative from research institutes (20%). Half of those indicating policy as a barrier identified that convincing and defending the effectiveness of introducing emerging technologies. The time and resource devotion for arguing the usefulness of new methods is a possible limitation for the effective success of ecological work. As new methods and technologies are often relatively unestablished, the protocol for their use is often lacking, which many experts believe to be a limiting factor for their successful establishment earlier in the technology's life cycle. It was identified by a representative from a wildlife charity that government and survey guidelines often constrict innovation. This was further corroborated by consultancy and charity representatives, as a third of those that identified policy and proposal processes as a barrier attributed it to outdated survey guidelines and best practice.

Cost benefit was seen as a barrier for 30.8% of representatives from industry, with a higher proportion of charity, government and research institutes compared to consultancy (Table 4). This barrier was mainly identified as a lack of funding for government and research institutions (2 representatives each). This sentiment is consistent with the current literature, with cost being a major deterrent for introduction (Hahn, Bombaci & Wittemyer, 2022). Where GIS was a staple of the industry, the introduction of paid alternatives to QGIS was seen as lacking in cost benefit, as the performance of free alternatives were viewed highly. Cost was a large barrier for the implementation of DNA analysis, including for citizen science approaches, as rolling out projects on large scales was not seen as feasible considering the high cost of DNA analysis. Cost as an important barrier was supported by recent research (Hahn, Bombaci & Wittemyer, 2022) highlighting its importance for the technological landscape and dictating technological adoption.

Lack of time to invest for researching and introducing new technologies was seen as a barrier for 26.9% of interviewees, with larger representation from consultancy and charity compared to government and research institutes (Table 4). 23.1% of interviewees, with equal representation from consultancy and research institutes also identified the technological landscape as overwhelming. Consultancy representatives also identified accessibility as a major barrier, specifically for specialist equipment, an example being the lack of accessible thermal cameras, which necessitate alternatives methods of use, such as renting. Renting also has its drawbacks, most notably having to invest in using technology for limited windows of time and travelling to collect them. The main barrier to the performance of Internet of Things was identified as the lack of stable and powerful infrastructure in maintaining effective connectivity in remote locations. For drones the only barrier referenced was potential privacy concerns, as their accessibility warrants knowledge and understanding of law surrounding where drone flights are permitted to avoid legal complications in surveys.

4.2.5.2 Challenges and issues with established technology

Analysis of technology-related challenges across ecological sectors revealed key difficulties influencing technology adoption and effectiveness. The high cost and associated repercussions emerged as the most commonly cited challenge, reported by 57.7% of participants. This issue was especially prominent in the charity (66.7%) and consultancy (63.6%) sectors, highlighting financial constraints that limit technology accessibility and sustained use in ecological applications (Table 5. For consultancy, charity and government, this challenge was attributed predominantly for the increasing cost of standard practice. Introducing thermal and infrared cameras as per the Bat Survey Guidelines, increasing the amount of both visual and acoustic sensors used for robustness, renting specialist equipment and employing external specialist were all seen as resource intensive. Investment in emerging technologies were identified as high risk for consultancy, charity and government due to lack of funding and long-term support. With the expanding repertoire of sensors, the computing power necessary for analysing data collected was also seen as resource demanding for charity. These increasing costs for standard surveys was identified as challenging for client relations for those in consultancy, as with larger numbers of expensive sensors, the time taken for surveys, and the cost of surveys increase, which some identified as frustrating for clients. These barriers were consolidated by recent literature (Hahn, Bombaci & Wittemyer, 2022) These costs might incentivise clients to instead illegally avoid surveys, as mitigating ecological impact is becoming less cost effective for clients, which hamper the ecological mitigation consultancies are able to provide. For government, costs were associated most frequently throughout emerging projects, namely in creating new models and methods using multiple facets of machine learning AI, and in upfront costs of specialist laboratory technologies, including 3D printing and PCR. The challenges documented across the consultancy, charity, government, and research sectors reflect both common and sector-specific hurdles in integrating technology within ecological work (Hahn, Bombaci & Wittemyer, 2022). High costs and related financial repercussions significantly impact the accessibility and long-term viability of newly introduced technologies, particularly in charity and consultancy sectors, where budgets are often constrained, especially for smaller teams. Addressing these financial barriers could involve the development of cost-effective technological alternatives or increased funding from both public and private stakeholders to support effective widespread technology adoption in resource deficient areas.

Table 5: Challenges and limitations in currently used technologies.

Challenges	Consultancy % (n=11)	Charity % (n=6)	Government % (n=4)	Research institute % (n=5)	Total % (n=26)
High cost and associated repercussions	63.6	66.7	50	40	57.7
Problems with data	45.5	50	50	60	50
Accuracy	63.6	66.7	25	0	46.2
Disconnect in developers and end users	63.6	16.7	75	20	46.2
Robustness and hardware limitations	36.4	83.3	25	20	42.3
Accessibility	18.2	33.3	50	80	38.5
Complexity and training difficulty	45.5	16.7	50	40	38.5
Labour intensiveness	54.5	16.7	25	20	34.6
Uncertainty	36.4	66.7	0	20	34.6
Lack of available support	27.3	16.7	50	40	30.8
Standardisation for new technology	27.3	33.3	50	20	30.8
Lack of available resources	36.4	33.3	0	20	26.9
Upskilling	27.3	0	50	40	26.9
Lack of connectivity between technologies	18.2	16.7	0	20	15.4
Lack of respect or knowledge	27.3	0	25	0	15.4
Pushback from developers for best ecological practice	36.4	0	0	0	15.4
Ethical considerations	9.1	0	25	20	11.5
High risk in implementing new methods and tech	9.1	16.7	25	0	11.5

Challenges	Consultancy % (n=11)	Charity % (n=6)	Government % (n=4)	Research institute % (n=5)	Total % (n=26)
Lack of resolution and scope	0	33.3	0	20	11.5
Overgeneralisation in classification tools	9.1	0	25	20	11.5
New tech can be overwhelming	18.2	0	0	0	7.7
Software performance i.e. crashing & slowness	18.2	0	0	0	7.7
Ineffective Internet of Things infrastructure	0	0	0	20	3.8
Legality and regulations	9.1	0	0	0	3.8
Misinterpretation of data	0	0	25	0	3.8

Problems with data were identified as a significant concern, noted by 50% of participants. Consistently present across sectors, data issues included difficulties in data quality, accessibility, and usability, with research institutions facing this challenge slightly more (60%) compared to other sectors. Similarly, accuracy concerns were frequently cited (46.2%), particularly in consultancy (63.6%) and charity (66.7%) contexts, where precision in ecological assessments directly impacts project outcomes and compliance with environmental regulations. These issues were predominantly identified in the size of data accumulated by emerging technologies and application:

"*Absolutely, yeah, a lot of it's just sorting through the kind of halls of data that we collect in the field? Yeah, this is where the time investment is definitely, yeah.*"

This was exhibited predominantly in field technologies such as thermal cameras and bioacoustics, where the lack of guidance for data storage protocol and analysis provide challenges for time devotion and efficiency of workers, and the environmental impact of holding the data (Monserrate, 2022). Data-related challenges emerged as another prominent issue, illustrating ongoing struggles with data management, processing, and quality assurance. With accuracy concerns also highly cited, there appears to be a clear need for technology that supports high-quality data collection and management, particularly in sectors like consultancy, where regulatory compliance is critical. Enhancements in data quality and accessibility, perhaps through improvements in bioacoustics and remote sensing accuracy, could help address these issues by enabling more precise ecological assessments.

A notable disconnect between developers and end users was reported by 46.2% of participants, underscoring sectoral differences in technology design and practical applications. Consultancy and government sectors, at 63.6% and 75% respectively, reported this as a major obstacle, indicating that technology solutions often lack considerations for specific ecological needs. These limitations were most apparent in technologies developed for other purposes, an example given being thermal cameras designed for plumbing, which was attributable to their decreased efficacy for identifying smaller species during surveys, which is particularly important considering these technologies predominant use for bat surveys. Biodiversity Net Gain as a division of data logging software was also referenced in regard to its development not meeting the needs for more niche industries, with a lack of consideration particularly for aquatic systems. Other ways this disconnect was voiced was in unintuitive UI for software like GIS and R, noted also as an issue with inherent complexity and an issue for training (38.5%) whereby effective use, especially for those new to the technology could be communicated better from developers, and decrease the high training requirements these technologies are associated with. Complexity was also a limitation for citizen science approaches, as standardising protocol for the public use of technology is difficult the more complex the technology is, namely highly sensitive eDNA kits and overwhelming mobile apps.

Hardware robustness and limitations also presented a significant barrier, with 42.3% of participants across sectors identifying this as a hindrance, particularly in the charity sector (83.3%). These limitations encompassed battery life and power consumption, as technologies develop and work better, faster, and resolutely, the necessary power increases. Accessibility challenges (38.5%) were also common, with research institutions experiencing the most pronounced issues (80%), due to specific demands for specialized, resolute training data and reference databases for training new models and software. Accessibility was also referenced as a physical barrier for Internet of Things and other connected devices, where infrastructure limitations exacerbate communication and data transmission (Mukhopadhyay & Suryadevara, 2014).

Labour intensiveness (34.6%) was another challenge, primarily observed in consultancy (54.5%), attributed most to quality assurance for eDNA techniques and identification apps, where uncertainty in outcomes necessitated time and resource devotion for validation and quality assurance. Uncertainty (34.6%), lack of available support (30.8%), and the absence of standardization for new technology (30.8%) were raised consistently across sectors, with charity participants particularly emphasizing uncertainty (66.7%). These challenges point to ongoing concerns about long-term technological stability and user support in ecological contexts, which has been referenced in other contexts, such as for business specialists (Wanderley & Silveria, 2012). Uncertainty and lack of support were often corroborated predominantly for software, where the breadth of options and outcomes for the ever-increasing slew of models and methods provide difficulty especially when the support is not yet effectively implemented for these newer technologies.

4.2.6 Desired improvements and recommendations for technology

Desired improvements in emerging ecological technologies across consultancy, charity, government, and research sectors are referenced in Table 6. A prominently identified recommendation was for enhancing and addressing communication, identified by 80.8% of interviewees, with consultancy, charity, and research sectors each indicating strong needs (90.9%, 66.7%, and 80%, respectively). This aligns with previous literature emphasizing effective communication as a need for advancing ecological practices and fostering collaborative technological efforts across various sectors (Hahn, Bombaci & Wittemyer, 2022). Communication was mainly divided into desires for improved guidance and training (69.2% of interviewees), and information sharing and collaboration (57.7%). These recommendations were supported by a recent broad survey and their importance corroborated by other ecological professionals (Speaker et al., 2022). Training and guidance improvements were voiced mainly for increased online and industry support for training and facilitating skills development in graduates. For the effective implementation of AI, improving industry understanding of AI was recommended by 34.6% of interviewees. This recommendation was further elaborated as addressing the negative connotations of AI and other technologies replacing surveyors (Faraca & Mustell, 2024), as many believed adversity towards these developments to be misunderstood and attributed to losing work. Information sharing and collaboration was voiced mainly for improved correspondence between industries, disciplines, and scientific journals. The potential of developments in these areas were cited as bolstering sharing of expertise for the effective use of technologies, a good example being interaction between technological developers to facilitate troubleshooting, understanding, and better considerations for technologies used by ecologists. This increasing complexity and specialisation in software has led to the necessity for IT specialists in many industries (Halász, Jámbor & Gubán, 2018; Zulauf & Knipprath, 2020). Better interconnectedness was also attributable to avoiding industries becoming siloed, instead exploring the potential for work done outside of their specific industry to be applied for theirs and vice versa. A desire for more considerations to be made for ecological applications of technologies was observed among 46.2% of participants, particularly within consultancy (72.7%). This indicated the importance for technologies that are specifically tailored to effectively address challenges faced within ecological work, rather than relying on more generalized tools. Precision and accuracy improvements were cited by 42.3% of respondents, with consultancy expressing the highest interest (63.6%). These recommendations were mainly aimed at sensitivity in camera traps and motion detection software for better capturing and identifying species of interest, more resolute EO dataset options, and automatic identification applications.

Standardization emerged as another desired improvement, with 53.8% of respondents identifying its importance. This was particularly relevant for government and research sectors (75% and 60%, respectively), which reflected a desire for unified protocols and guidelines that enhance interoperability and reliability in technologies for data management and acquisition. These recommendations were aimed at incorporating and circulating data standards for surveys, and interdisciplinary standardisation of shared technologies and their applications. Similarly, best practice development was seen as essential by 50% of participants, suggesting a sector-wide recognition of the need for well-defined standards and benchmarks in ecological technology usage, especially in charity and consultancy sectors (66.7% and 54.5%, respectively).

Table 6: Identified improvements to emerging technologies expressed as important by individuals in the ecology sector.

Desired improvements	Consultancy % (n=11)	Charity % (n=6)	Government % (n=4)	Research institute % (n=5)	Total % (n=26)
Communication	90.9	66.7	75	80	80.8
Standardisation	45.5	50	75	60	53.8
Best practice	54.5	66.7	25	40	50
Bespoke for ecology	72.7	50	0	20	46.2
Precision and accuracy	63.6	50	25	0	42.3
User friendliness	36.4	50	50	40	42.3
Availability and accessibility	18.2	66.7	50	40	38.5
Hardware improvements	45.5	33.3	0	20	30.8
Experience in technology use	9.1	16.7	50	40	23.1
Affordability	27.3	0	0	0	11.5
Improving the signal of remote sensors	0	0	25	40	11.5
Better connectivity between technologies	9.1	0	0	0	3.8

User-friendliness (42.3%) and availability and accessibility (38.5%) were also highlighted, reflecting a broader push towards making technology more inclusive and easier to operate across skill levels. Charity sector respondents were particularly vocal about accessibility (66.7%). The push for accessibility came mostly from the desire for more open source and commercial options for technology, as specialised equipment can be prohibitively expensive and difficult to circulate on large scales, as seen by those identifying affordability (11.5%) as a key area to improve. The desire for open-source technology has been similarly documented for GIS tools for landscape ecology (Steiniger & Hay, 2009). Accessibility was also referenced in regard to data availability, with a desire by industry for more options of more resolute datasets, examples mentioned being reference databases for machine learning, and aerial imagery datasets.

Improvements mentioned less frequently included hardware improvements (30.8%). While hardware improvements were still relevant, they were not uniformly prioritized across sectors. Current hardware limitations were identified in field sensors predominantly, examples being bioacoustics, and camera traps, which would benefit for longer autonomous surveys if improvements were made to their battery and storage capacities, and to their robustness. Improved storage was also reference as being possibly alleviated with developments to the capability of more sensors for effective telemetry options. These sensors were also referenced in regard to signal issues (11.5%) where developments to signal infrastructure would alleviate the risk of losing important data during long-term autonomous field surveys and facilitating better correspondence and connectivity in devices during surveys.

Overall, the findings indicate a strong emphasis on communication, standardization, and sector-specific customization, with a clear corroborated desire for improvements that directly enhance the usability, accessibility, and precision of technologies within ecological fields. These insights could inform future technological development and policymaking to better align with the needs identified by practitioners across these sectors. Despite focal research for desired technological improvements (Hahn, Bombaci & Wittemyer, 2022) the lack of industry focus is an important current limitation which should be addressed in conjunction with the findings of this research.

4.2.7 Training and early career ecologists

4.2.7.1 Recommended skills and experience for graduates

For those attempting to, or considering entering ecological industry, the recommendations made by industry workers can be categorised as soft skills, skills specific to ecology, and specific technological experience. Soft skills were often deemed as paramount, critical thinking and thinking logically being referenced the most. A strong ability to use the scientific method effectively and show ingenuity is heavily sought after, especially when working with technology, as being able to troubleshoot and think methodically about how best to utilise your resources in turn expediates the necessary training that has to be administered by industry following hire:

"And do I feel like that I can kind of sell that to employers, but, but actually, you know, there are a lot of skills, you know, throughout university, but also through doing the MRes that are applicable to consultancy, you know, like being accurate and recording data, written communication"

Concurrently adaptability and the capability to embrace failure and learn from it is important. These skills were referenced frequently in conjunction to enthusiasm and a desire to make a difference in the field. As ecology is an industry that encapsulates working for the betterment of the environment and organisms, possessing the drive to want to do the best work possible is massively desirable. Being able to communicate effectively is especially important, with consultancy as a prime example, as corresponding with colleagues and clients facilitates an effective working environment.

For skills and experience specific to ecology, having a good conceptual understanding of ecology was referenced extensively. Understanding habitat health and classification, possessing good identification skills, and understanding botany were referenced. To make the most effective use of technology, understanding the ecology behind their application is increasingly important, and was generally found to be secondary to specific technological experience. Particularly for those aspiring to join consultancy or government, having a good understanding of policy and law specific to ecology is incredibly useful. Generally, having an aptitude with working with, manipulating, and understanding data is paramount for being an effective industry worker. Being able to disseminate and effectively communicate findings facilitates effective education and client relations. Effective data collection in the field is particularly important, both in data standardisation and understanding what data is necessary for particular technological applications. Given the advent of larger data sets, automated data analysis, and new types of data arising from technological developments, knowing how to handle and troubleshoot data is a massively important skill to have for any type of ecological industry.

4.2.7.2 External experience

The recommendation for graduates to engage with external opportunities for skills development and experience had its merits endorsed. Sources of external online resources for skills developments are abundant, and it is encouraged to make use of the internet and external scientific bodies, as recorded conferences, webinars, and talks are an accessible and cost-effective resource for facilitating an effective transition to industry, especially considering many of the resources have direct tie ins to industry, such as CIEEM. Volunteering is another encourages avenue to explore, as learning hands on, practical experience is paramount for understanding how ecological industries function. Volunteering is not accessible to everyone, and it is encouraged that industries do more to alleviate this issue. It was the belief of many that the potential lack of engagement with industry may be enough to discourage those who might be excellent candidates but were unable to gain the practical experience necessary.

4.2.7.3 Recommendations for University

The most requested recommendation for universities was to fully explore and disseminate the applicability of both emerging and established technologies as used by industries. The incorporation of technology into academic learning is massively encouraged, especially for engaging students (Barnett et al., 2011). The importance of following and keeping up to date with the technological landscape in university curriculums is paramount, and it is encouraged that students should be made aware of technological applications for industries. Providing context of all possible avenues graduates can take following graduation is recommended, as the transition from university to industry can be overwhelming (Jose Cabral-Cardoso, 2001). Considerations for ecological industry can often be underrepresented in teaching, with some believing specialisation and specificity in modules and courses to be too restricting. For technological experience, recommendations were made for more freedom in project design. Teaching in software critical for industry, such as GIS and programming, are often perceived as underutilised, where fully exploring the capabilities of these technologies in a more practical setting is encouraged. The transition from using this software for research to industry can be difficult, as students can get pigeonholed into only understanding their application for cases specific to research. Oftentimes graduates have experience using technologies from university, but the transferability is absent as they can only utilise them in specific cases Bembridge, Levett-Jones, & Jeong, 2011). The importance of maintaining an effective foundation for university teaching is paramount, as these foundational skills are what expediates effective experience in using technology. Despite the rapid developments to the technological landscape, and the experience of more recent generations in developing technologies, many believe that having the basis in the technologies likely to never be replaced, i.e., Microsoft Word and Excel, is crucial and not to be underrepresented:

"I think there probably is a bit of a change. I think generally graduates are becoming more skilled in some technologies, but potentially also less skilled in others. Probably things like general use of like Microsoft Word and stuff…"

It is recommended for biological curriculums to improve collaboration and experimentation in technologies associated with adjacent fields earlier on in degree schemes, a frequently referenced example being GIS. It was the shared concern of many that GIS was an underutilised resource in their university degrees and is recommended to be incorporated earlier on in the degree scheme. The incorporation of AI was mentioned frequently, with those recommending more resources dedicated to understanding and embracing the capabilities of applying large language models and other AI tools. The application of AI has high potential especially considering its compatibility both with facilitating novel approaches to data analysis, and for improving understanding and dissemination of complex programming. Embracing large language models and understanding how to use them effectively is an incredibly interesting resource to utilise. Being too quick to dismiss AI entirely is discouraged, as educating and understanding how best to use it can facilitate the effective use of a cutting edge, incredibly powerful resource (Abassi, Wu & Luo, 2025). Despite the improved representation new and emerging technologies get both in industry and academia, the predominant issue raised by this project is the lack of interface and correspondence between these two facets of ecology. For the effective assimilation of university graduates into industry, there must be a mutual understanding in the wants and desires of industries from academia. With an improved focus on the technologies that facilitate effective work being done on behalf of animals and the environment, partly from research similar to this, better integration of these technologies is possible in curriculums that will bolster the experience and knowledge of the next generation of early career ecologists.

5.0 Conclusions

There is a strong emphasis within ecological industry on the need for improved communication and training within industries, as many stressed the importance of effective communication in advancing ecological practices and fostering collaboration. The desire for enhanced guidance and training is supported by the frequently stressed need for sector-wide, accessible training resources that can support the smooth transition both into industry for early-career ecologists and for seasoned professionals to keep up with developments and successfully adopt the maximally beneficial technologies for ecology and conservation. More considerations are desired for standardization and best practices, particularly within government and research sectors. Uniformity in protocols and data standards for technologies were identified as foundational for data integrity, reliability, and cross-sector interoperability. This finding suggests that the establishment of universally recognized guidelines could streamline the most successful technological adoption, enhance the best standard for their use, and facilitate effective knowledge exchange between sectors.

The need for more specialized and ecologically tailored tools is apparent for ecological industries, particularly within consultancy. Precision and accuracy improvements are also critical for the enhanced sensitivity and resolution in key tools such as camera traps, motion detection software, and remote sensing devices. Industries require innovations that can reliably capture and analyse ecological data, especially over larger scales and for longer time frames. User-friendliness and accessibility surfaced as critical considerations, especially in the charity sector, where respondents highlighted the barriers posed by specialized, often costly equipment. Open-source and more affordable commercial options were recommended for improving inclusivity and ensuring that technology can be feasibly adopted and used by a broader range of practitioners, not just those interested in field work. Relatedly, the accessibility of high-resolution datasets and training data for bespoke AI models was also cited for its potential for improved ecological research and analysis, allowing ecologists to derive meaningful insights from increasingly complex data. Where there are increases in the data acquired, there must also be concurrent effort put into the analysis and dissemination, particularly when using ecological results to inform or educate others.

Lastly, this project emphasizes the importance of training future ecologists with relevant skills and experience for their integration with ecology. Soft skills are paramount for working with technology: critical thinking, adaptability, and effective communication were identified as fundamental. Technical skills, particularly in data handling, field data collection, and technological proficiency were favoured but . Recommendations for universities to integrate emerging technologies like AI, remote sensing and GIS, and programming earlier in academic programs could facilitate the effective transfer from academia to ecological professions. Keeping up with the technological landscape and providing opportunities for students to explore what technologies are on offer, and what they can be used for is critical, but industries must improve their responsibility for disseminating their requirements from graduates and providing the support necessary for their successful integration.

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7.0 Appendices

7.1 Appendix 1: Additional information encompassing emerging technologies for ecology and conservation.

Technology	Description	Types of data	Application	Positives	Challenges/limitations	State
Camera traps	Composed of a digital image sensor, PIR sensor to proximally detect heat, and auxiliary electronics. Can range in price from cheap (~$50) to expensive (~$1000) depending on abilities (image quality, triggering delay).	Images & video	1. Species monitoring. 2.1 Population status monitoring. 2.2 Species presence/ absence. 2.3 Species detection rate calculation. 2.4 Individual monitoring: artificial or natural markings. 2.5 Searching for rare species. 2.6 Estimating biodiversity. 2.61 Community diversity. 2.62 Local diversity.	Non-invasive sampling. Facilitates obtaining natural behavioural data. More precise and accurate than eyewitness. Human presence obscuring/augmenting data nullified. Can mark tracks and faeces. Can be deployed for long term data collection.	Weather can affect data collection. Scope of captured images can be limiting without forethought or complications. Typically do not trigger on smaller species (<50g) or poikilothermic species. Larger species hard to identify due to insufficient motion sensors or slow triggers. Can fail to sample entire communities or omit individuals. Groups of communities can be difficult to identify when similar species occupy the same locale. Humidity can damage electronics. Small invertebrates can infiltrate and damage the cameras. Large species can destroy/displace cameras.	Established and developing.

			2.7 Habitat preference. 2.8 Behavioural sampling. 2.9 Species abundance. 2.10 Species density. 2.11 Occupancy. 3 Threat detection. 3.1 Monitoring poachers. 3.2 Monitoring invasive species. 3.3 Predator prey dynamics.		Camera theft, vandalization.	
Acoustic sensors	A sound recorder with an associated micro/hydrophone.	Sound recordings	1. Species monitoring. 1.1 Monitoring vocal individuals. 1.2 Wildlife tracking. 1.3 Behavioural assays. 1.4 Measuring acoustic spatial, temporal and	Can track animals that are vocally expressive. Does not require the presence of humans when collecting data. Does not rely on sight of animals. Can make inferences on group size, behavioural expression. Can be used when visual detection is limited. Can be deployed for long term data collection.	Some data analysis methods require training data. Passive acoustic monitoring requires a lot of forethought: non-standardization of monitoring protocols, labour-intensive acoustic analyses, and limited data curation. Can be very energy demanding for long recordings, both for power supply, and data storage.	Established and developing.

			frequency patterns in response to biotic/abiotic factors. 1.5 Use acoustic composition to assess biodiversity, habitat integrity, and threats to species. 1.6 Measuring ranging, territoriality, and activity patterns. 1.7 Ecoacoustic indices. 1.8 Soundscape generation. 1.9 Vocal identification. 1.10 Endang ered and invasive species identification. 2.0 Human impact studies.	Require low research hours (no frequent visitation required). Can be used in adverse weather situations. Devices have become more affordable and smaller (less intrusive) over time with tech advances.	Data processing made difficult by the large datasets generated by continuous recording samples (manual analysis not recommended, necessitating algorithms and machines). Costs of shelf devices (additionally power supplies and storage devices for large data) can be very high.	

Remote sensing	Air/spaceborne platforms that can produce extensive, vast images of habitats and large terrains which is then transmitted back to relay stations to be analyses.	Georeferenced images (RGB, thermal, multi, or hyperspectral)	Wildlife tracking. Obtaining detailed spatial and temporal data on land cover and geography. Large scale geographic conversion, modification, and fragmentation analyses. Physical composition mapping (canopy/tree height).	Ground based platforms are good at obtaining detailed data from one point but cannot collect aerial perspective data of a larger region, which aerial and spaceborne platforms can.	Incorporating EO products into conservation management practices. Budget, information sharing, decision makers and policy change are not technology reliant, but can halt research efforts. Cloud coverage limits aerial data acquisition in certain conditions/seasons. Arctic surveys can be troublesome during certain parts of the year with periods of continuous darkness. Some analyses require higher resolution than satellites offer presently. When higher resolution data are available, cost can be exorbitantly higher. Often require specialist geographic information system (GIS) and/or remote sensing software.	New and emerging
Drones (UAVs)	Split into three categories: **fixed-wing, multirotor, and hybrid VTOL (vertical**	Aerial georeferenced images & video (RGB,	1. Animal counts 1.1 Determining distributions or densities. 2. Mapping.	Allows for better identification of individuals where traditional methods might be limited, e.g. identification of species high up in canopies where ground surveillance is likely to miss	Manual detection of objects of interest (poachers, cars, species) can be time consuming and costly.	Emerging. Used to some capacity already.

	take-off and landing). Include three important components: **power source, flight controller, and ground control station.**	thermal, multi, or hyperspectral)	2.1 Mapping land-cover classification and land-cover change detection. 3. Poacher detection 3.1 Illegal animal hunting 4.11 Meat. 4.12 Body parts.	individuals compared to an airborne view.	Canopy can severely limit airborne effectiveness of data collected, i.e. orangutan nests. When thermal cameras are used, difficult to differentiate similarly sized species. Differentiating poachers from other heat emitting objects using thermal cameras difficult. Data transmission over long distances can be challenging.	
Animal borne devices	Devices carried by animals that collect or transmit data for research.	Location data of animals	1. Species monitoring 1.1 Species movements 1.11 Migrations. 1.2 Species behaviour 1.21 Habitat preference 1.22 Foraging strategies 1.23 Social interactions 1.3 Energetics	Exploring the movements or behaviours of animals that are too difficult to monitor with traditional methods due to costs, data acquisition challenges. Builds upon traditional capture, mark, recapture methods, or visual observations following intensive manual tracking or opportunistic encounters. We can assign different specific radio frequencies to different individuals for individual tracking. Trackers are flexible considering the size of the	Some must be reclaimed to access the information collected, if the device is not connected or relayed to an external receiver, i.e. satellite transmission or relay tower. Proximity can be a limiting feature for some tags, but limitations can be mitigated if research properly coordinated, i.e., receivers can only pick up transmissions from ~50m but are placed in areas of interest like foraging patches so information is only collected at the specific sites.	Traditional and developing.

				species of interest and the non-invasiveness of newer smaller tags.	Animals must be captured initially for any method of animal borne tracking, which can be costly and labour intensive, and dangerous depending on the species.	
eDNA	The science of taking environmental samples (soil, water, air) or using biological alternatives for measuring biodiversity (leeches, carrion flies) then obtaining DNA through concentrating, isolating, and testing through PCR in a laboratory setting. eDNA is collected environmentally so as not to be invasive.	DNA records	1. Biodiversity documentation. 2. Invasive species detection. 3. Pathogen detection. 4. Species of conservation concern detection.	Detecting species that occur in low numbers or elusive species. Obtaining samples is non-invasive and as such does not require invasive methods and additional technology/labour.	Prior to field analysis validation must be conducted both in the form of known taxa shed DNA to validate the operation of eDNA analysis with known quantities of DNA and to avoid cross amplification with other species. It is not yet possible to identify all individuals within a sample of eDNA using next generation sequencing. Different species shed DNA at different rates, and DNA persistence is limited by environmental variables such as UV exposure which may fluctuate over time. eDNA is not homogenously distributed. Currently we are unable to quantify population size from eDNA analysis.	Developing.

Field and lab analysis technology.	Field spaces involving sample preparation and preservation, and on-site laboratory analysis.	Molecular/physiological indicators.	1. Understanding habitat requirements. 1.1 Examining diets. 1.2 Nutritional content of foods. 1.3 Habitat specific nutritional intake. 1.4 Habitat quality (availability of micro/macronutrients. 2. Understanding species physiology and disease status. 2.2 Effect of anthropogenic disturbance on wildlife health, distribution, long term viability. 2.3 Parasite/pathogen analyses	Modern advancements are relying less on strict ex situ analysis and facilitating on site or remote analysis of data collected in the field. Advancements in the preservation and holding of samples.	Facilitates time effective and accessible analyses, which can be done remotely and do not require the investment in transportation and storage associated with external laboratories.	Traditional and developing.

Mobile devices and applications	Handheld portable devices that can remotely access the internet.	Many types of data (i.e. images, video, location) from a myriad of sensors and applications.	1. Data entry. 2. Data playback and communication. 3. Species identification. 4. Accessing information via the internet.	Allows for less erroneous data collection and storage. Increasing availability and flexibility of specs and additions to phones, combined with their increased durability and lower costs. Citizen science is a massive compliment to mobile devices as sharing is made much easier through the multitudes of social platforms that are becoming increasingly available. Open-source data and information have made the dissemination and sharing of information incredibly easy, especially considering the standardization between global usage of mobile devices allowing similar access to these materials.	The rate at which new apps and operating systems are developed means that regular updates must be conducted to maintain certain platforms from becoming obsolete or incompatible. The lack of updating is not necessary always, but necessary troubleshooting and functionality issues can go unresolved if the app is made incompatible through a development in the operating system.	Traditional with new and emerging alternatives.
AI & computer vision	CV is the field of computer science that use computer algorithms to derive useful information	Recorded identification/recording from process	1. Machine learning 1.1 Image classification 1.2 Object detection	Machine learning: Allowing a shift from manual human error limited analysis of data (both numerical and image based) to fully autonomous analysis.	Algorithms require training. Most of the benefits of ML algorithms have been with desirable images, but the generalizable classification of low-quality images (poor lighting, low resolution) is	Emerging

	from still images or videos. CV can also work to make data acquired from images or videos more digestible for humans, i.e. deriving the 3-dimensional structure of images for geographical analysis.	ed images.	2. Outcomes for wildlife monitoring programmes. 2.2 Protected area planning. 2.3 Allocating anti-poaching resources. 2.4 Advising governments and industries on the impact of human development.	Most applications of successful ML learning have been coarse in its identification, i.e. recognising distinctly dissimilar species. Fine grained classification is more relevant for more conservational goals but is challenging given the subjective similarity in the desired outcomes. Fine grained classification bolsters huge benefits for accelerating the workload of conservation projects and goals. Data collected through developing technologies, i.e. camera traps, drones, bolster far larger and more complex data, which are often limited through human analysis being labour and time intensive. Automation facilitates the acceleration of these analyses without need for human input, except for algorithm training prior to analysis. Identification to species level is critical for conservation goals, and ML allows fine scale identification.	paramount, as often outcomes from technology producing images are subject to undesirable and uncontrollable environmental conditions.	

				The identification of subtle individual differences in species, i.e., sex and age-related morphology, is critically important for research, where fine grained classification is key to allowing these analyses.		

7.2 Appendix 2: Survey template.

New and emerging technologies in the ecology and conservation sector

2024

Swansea University's Biosciences Department is conducting research on emerging technology in the ecology sector to evaluate and explore both current and future technology use. We are interested is assessing how this information can be used to inform curriculum design in Higher Education and early career training.

Section 1: Demographics

In this section we aim to collect some demographic information as well as information surrounding your role within your organisation. Please note that all information provided in this survey will be anonymized and any information will be held secure under a password protected excel document and destroyed after 10 years following the finalization of this research.

1.Organization name. Required to answer

…………………………………………………………………………………….

2.Type of organisation: Single choice. Required to answer.

Charity

Consultancy

Local government

National government

3.Briefly describe your role within the organization:

…………………………………………………………………………………….

4.Years spent as a professional within the ecology and conservation sector. Required to answer.

…………………………………………………………………………………….

5.Age. Required to answer.

18-25

26-40

41-55

56-65

66+

6.Please provide a general overview of your organization's main areas of activity. Required to answer

…………………………………………………………………………………….

7.Approximately how many employees are there in your company? Required to answer.

…………………………………………………………………………………….

8.Years active (i.e. how long has the company been operating). Required to answer.

…………………………………………………………………………………….

Section 2: Your use of technology

In this section, we aim to ascertain what technologies are being used and practiced within the conservation and ecology industry. We are defining technologies as the equipment, digital or physical, that are specific to your operations, i.e. camera traps, acoustic monitors, specific data processing tools (i.e. R studio & QGIS). Technologies that are not included are the more general day to day technologies, i.e. PC's, Microsoft Excel, and mobile phones, but any specialised software (i.e. apps and programmes) for ecology/conservation are included.

10.Please select the technologies you work with, and how often you use them in your work. Required to answer.

	N/A	Never	Rarely	Occasionally	Frequently	Every day
Camera traps						
Acoustic sensors						
GIS/remote sensing						
Drones/UAVs						
Animal borne biologgers/trackers						
Terrestrial/aquatic vehicles						
eDNA						
Mobile apps						
Networked sensors						
Data processing/ management tools (e.g., coding, simulation, and programming software)						
Artificial intelligence						
Machine learning						
Big data analysis						
Data mining						

	N/A	Never	Rarely	Occasionally	Frequently	Every day
3D printing						
Augmented VR						
Virtual fencing						
Advanced robotics (e.g. autonomous vehicles)						
Other sensors (Internet of Things, long distance communication)						

11.Please select the technologies you work with, and your level of proficiency with them. Required to answer.

	N/A	No proficiency	Novice	Intermediate	Advanced	Expert
Camera traps						
Acoustic sensors						
GIS/remote sensing						
Drones/UAVs						
Animal borne biologgers/trackers						
Terrestrial/aquatic vehicles						
eDNA						
Mobile apps						
Networked sensors						
Data processing/ management tools (e.g., coding, simulation, and programming software)						
Artificial intelligence						
Machine learning						
Big data analysis						
Data mining						
3D printing						
Augmented VR						
Virtual fencing						
Advanced robotics (e.g. autonomous vehicles)						
Other sensors (Internet of Things, long distance communication)						

12.If there are any technologies you feel are missing above, please include them here, as well as your proficiency with them.

…………………………………………………………………………………….

13.We are trying to explore how recent the technology that is currently used within the industry has seen developments/updates, or if any of the technologies currently being used are new/emerging. Which statement best describes the technologies you use? (*developments could include newer models or additional components to established technologies, i.e. infrared capabilities for optical cameras*). Required to answer.

	N/A	Has not seen any recent developments/updates	Somewhat recently developed/updated	Very recently developed/updated	New/emerging
Camera traps					
Acoustic sensors					
GIS/remote sensing					
Drones/UAVs					
Animal borne biologgers/trackers					
Terrestrial/aquatic vehicles					
eDNA					
Mobile apps					
Networked sensors					
Data processing/ management tools (e.g., coding, simulation, and programming software)					
Artificial intelligence					
Machine learning					
Big data analysis					
Data mining					

	N/A	Has not seen any recent developments/updates	Somewhat recently developed/updated	Very recently developed/updated	New/emerging
3D printing					
Augmented VR					
Virtual fencing					
Advanced robotics (e.g. autonomous vehicles)					
Other sensors (Internet of Things, long distance communication)					

14.Please briefly explain your answer to the previous question. Required to answer

………………………………………………………………………………….

15.What conservation efforts do the technologies you use best support? (*please select all that apply*) Required to answer. Multiple choice.

Wildlife monitoring

Habitat monitoring

Threat detection

Land cover classification

16.Please briefly expand on your answer to the above question (*i.e. any differences in uses between different technologies).*Required to answer.

…………………………………………………………………………………….

17.How would you rate your overall satisfaction with the performance of the technology you use? Required to answer. Single choice.

Completely satisfied

Satisfied

Neutral

Dissatisfied

Very unsatisfied

18.Please briefly expand on your answer to the above question (*i.e. any differences in performance between different technologies).*Required to answer.

…………………………………………………………………………………….

19.What are the top 5 most important/sought after properties of the technologies you use? Required to answer. Multiple choice.

Accessibility

User friendliness

Upfront cost

Ongoing/maintenance cost

Durability

Flexibility

Customizability

Precision of data

Accuracy of data

Non-invasiveness

Alleviation of labour

Time effectiveness/devotion

Performance

Training requirements

Security and privacy

20.Please briefly expand on your answer to the above question (*i.e. any differences in uses between different technologies).*Required to answer.

…………………………………………………………………………………….

21.Where do you find the technologies you use are currently limited or provide challenges? Required to answer. Multiple choice.

Accessibility

User friendliness

Upfront cost

Ongoing/maintenance cost

Durability

Flexibility

Customizability

Precision of data

Accuracy of data

Non-invasiveness

Alleviation of labour

Time effectiveness/devotion

Performance

Training requirements

Security and privacy

They have no limitations

22.Please briefly expand on your answer to the above question (*i.e. any differences in limitations/challenges between different technologies).*Required to answer.

…………………………………………………………………………………….

23.Please select any technologies you do not currently use, but could see merit in using. Multiple choice.

Camera traps

Acoustic sensors

GIS/remote sensing

Drones/UAVs

Animal borne devices

Terrestrial/aquatic vehicles

eDNA

Mobile apps

Networked sensors

Data processing/ management tools (e.g., coding, simulation, and programming software)

Artificial intelligence

Machine learning

Big data analysis

Data mining

3D printing

Augmented VR

Virtual fencing

Advanced robotics (e.g. autonomous vehicles)

Other sensors (Internet of Things, long distance communication)

None

24.If you listed any technologies for the above question, what is limiting their use presently? Multiple choice.

Accessibility

User friendliness

Upfront cost

Ongoing/maintenance cost

Durability

Flexibility

Customizability

Precision of data

Accuracy of data

Alleviation of labour

Time effectiveness/devotion

Performance

Training requirements

Security and privacy

Section 3: Perceptions and views of the conservation technology landscape.

In this section we aim to establish how people working in ecology/conservation view the state and trajectory of the technological landscape now and in future.

25.Given the emergence of new/rapidly developing conservation technologies, do you feel more or less optimistic for the future of conservation technology? Required to answer. Single choice.

More

Neutral

Less

26. (If answer to Q25 was More or Neutral) What makes you feel the most optimistic for the future of conservation technology? (*rank from most to least optimistic*). Ranking.

Technology is rapidly developing

The advent of brand-new technologies

More support from conservation industries, communities and decision-makers

Involvement of big tech/big data

Improved collaboration culture

27. (If answer to Q25 was Less) What makes you feel the least optimistic for the future of conservation technology? (*please rank in order of least to most optimistic).* Ranking.

Increasing costs of new/developed technologies

Privacy/ethical concerns

Developments not being made in the right areas

Accessibility to new/developed technology

28.Which of these best describes the current trajectory for new/developing technology for your industry? Required to answer. Single choice.

New technology is already/frequently being introduced

Actively preparing for the introduction of new technology

Optimistic but not currently looking to introduce new technology

Apprehensive for their introduction (they raise concerns, privacy, ethical etc.)

Apprehensive for their introduction (they require further development/testing)

Uninterested in their introduction

29.For the technologies used below, do you think they will be used more, less or the same in future? Required to answer.

	Less	The same	More
Camera traps			
Acoustic sensors			
GIS/remote sensing			
Drones/UAVs			
Animal borne biologgers/trackers			
Terrestrial/aquatic vehicles			
eDNA			
Mobile apps			
Networked sensors			
Data processing/ management tools (e.g., coding, simulation, and programming software)			
Artificial intelligence			
Machine learning			
Big data analysis			
Data mining			
3D printing			
Augmented VR			
Virtual fencing			
Advanced robotics (e.g. autonomous vehicles)			
Other sensors (Internet of Things, long distance communication)			

30.Please briefly explain your answer to the above question. Required to answer.

…………………………………………………………………………………….

Section 4: Early career/graduate skills development.

This section aims to establish what teaching and skills are currently being implemented, and what training changes could be beneficial, for people working with technology in the conservation and ecology sectors.

31.For the technologies currently used within your organisation, which statement best describes the learning process for working with technology? Required to answer.

	Dedicated training programmes within your workplace	Working alongside experienced colleagues	Self-directed learning using manuals/online resources	Experience is an essential skill sought after prior to hire	Training is not generally required
Camera traps					
Acoustic sensors					
GIS/remote sensing					
Drones/UAVs					
Animal borne biologgers/trackers					
Terrestrial/aquatic vehicles					
eDNA					
Mobile apps					
Networked sensors					
Data processing/ management tools (e.g., coding, simulation, and programming software)					
Artificial intelligence					
Machine learning					
Big data analysis					
Data mining					
3D printing					
Augmented VR					

	Dedicated training programmes within your workplace	Working alongside experienced colleagues	Self-directed learning using manuals/online resources	Experience is an essential skill sought after prior to hire	Training is not generally required
Virtual fencing					
Advanced robotics (e.g. autonomous vehicles)					
Other sensors (Internet of Things, long distance communication)					

32.Do you foresee any changes having to be made regarding training for new and emerging technologies, and if so, what changes? Required to answer.

…………………………………………………………………………………….

33.Please select from below any limiting factors you foresee in delivering training for emerging/developing technologies? Multiple choice.

Access to quality training

Cost of administration

The technological landscape changes too quickly for the technology

Insufficient time to devote for optimal training

The technology is excessively difficult to train people on

34.What experience/training in working with conservation technologies would you recommend most for new hires attempting to join your industry? Required to answer.

…………………………………………………………………………………….

35.Where would you advise early career and graduates to gain the skills they need in conservation technologies? Required to answer.

…………………………………………………………………………………….

36.Thank you for your participation, we appreciate the time you've taken in completing this questionnaire. If you would be willing to participate in an interview, please could you provide your name and contact details below.

…………………………………………………………………………………….

7.3 Appendix 3: Interview questions template.

Introduction and establishment of research aim.

Current technology

What is the nature of your engagement with technology?

Which technologies do you currently use?

How proficient would you say you are with them?

How do you use technology for conservation and ecology? (e.g. fields, efforts)

How does the technology help you benefit conservation and ecology?

How important is technology for your conservation work?

What is working well with this technology?

What aspects of the technology do you value most?

What kind of challenges do you experience with these technologies?

How would you address these challenges?

Are there any trade-offs with its values and limitations?

Where would you most like to see improvements or developments in the technology you currently use?

New technology

What do you consider new and emerging technology for your field?

Are there any new and emerging technologies you are using or considering using?

Do you think emerging technologies could be used to address conservation concerns more effectively?

Are there any particular aspects of conservation work you think would benefit most from emerging technologies? Analysis, fieldwork etc.

Could you see yourself replacing any currently used technologies with newer models or novel technologies?

> What are the benefits of newer technologies over the currently used ones?
> Are there any aspects that you find lacking?
> If not, what would have to change in order for you to consider using them?

Do you foresee any challenges with implementing new/emerging technologies? (e.g. cost, expertise, training, specificity of maintenance, etc.)

How many resources do you dedicate towards technology have changed over time?
    More resources for new technology or developments?

How do you see the tech landscape changing in the future?

If all limitations/concerns were addressed, how good to have would this technology be for conservation efforts?

Training

Do you currently provide training for work with technology?

What are your expectations from new hires in experience with the technology you currently use?

What level of education and experience do you typically expect from a new hire?

Do you see the need for additional training for developing/emerging technology?

Do new graduate hires typically have the necessary experience and knowledge with working with technologies?
    How do you think that University curriculums could better prepare Biosciences graduates for working in your industry?

Do you see your repertoire of desirable skills/expertise changing given the advent of new technology/developments to current technologies?

Final thoughts and feedback

7.4 Appendix 4: Project codebook.

See: Emerging technology in ecological industry.xlsx for the full NVivo codebook for this project.

7.5 Appendix 5: Survey results.

See: New and emerging technologies in the ecology and conservation sector(1-10).xlsx for the full results of the survey.

7.6 Appendix 6: Project log proforma

Name of Student (print)	Jac Hicks Jones
Student Number (print)	[redacted]
Degree Scheme	Biosciences MRes
Title of Project	Emerging technologies in the ecology and conservation sector.

A single draft of this work was submitted and commented on ☐

A partial draft of this work was commented on ☒

A draft of this work was not submitted ☐

A draft of this work was submitted too late to comment on ☐

ACTIVITY	DATE	STUDENT'S SIGNATURE	SUPERVISOR SIGNATURE
Introductory meeting	9/11/23	[redacted]	[redacted]
Conformation of project	13/11/23		
Meeting	10/1/24		
Meeting w/ second supervisor	22/1/24		
Meeting w/ second supervisor	26/1/24		
Meeting: risk assessments	29/1/24		

Meeting: consent forms	**30/1/24**	[redacted]	[redacted]
Meeting: ethics	**2/2/24**		
Meeting: general planning	**16/2/24**		
Meeting: ethics	**26/2/24**		
Meeting: progress	**1/3/24**		
Meeting: progress	**7/3/24**		
Meeting: progress	**22/3/24**		
Meeting: interviews & questionnaire	**15/4/24**		
Meeting: participants	**30/4/24**		
Meeting: catch up	**16/5/24**		
Meeting: catch up	**20/5/24**		
Meeting: catch up	**17/6/24**		
Meeting: methods	**14/7/24**		
Meeting: catch up	**26/7/24**		

Meeting: write up	**5/8/24**	[redacted]	[redacted]
Meeting w/ second supervisor	**7/8/24**		
First draft meeting	**12/9/24**		
Meeting	**18/9/24**		
Final meeting	**29/10/24**		

Continue on more pages, if required.

We sign that the above is a true record of our meetings in relation to the project.

Name	**Signature**
Student:	[redacted]
Supervisor:	[redacted]