

Image source: Mike Svetik

Using Smart Contracts to Attract Conservation Investment



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Abstract

The conservation sector is facing a financial crisis. It is underfunded by billions of dollars, motivating conservationists to find alternate funding sources. It has been suggested that attracting private capital in the form of investment could solve this problem. This dissertation explores the question: can smart contracts (computer programmes that automate the transfer of funds and digital representations of objects) be used to attract conservation investment? Exploratory research into what smart contracts can afford to conservation and the creation of a model smart contract using the European Wildlife Bank as a case study were used to answer this question. It is concluded that although technologically possible to attract investment, this application is limited in scale and will not solve the financial crisis. It is recommended that the conservation sector continue to explore emerging technologies to identify more feasible solutions.

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1. Introduction

Over the past few years, society has witnessed a growth in technological capability. Artificial intelligence (AI) has made an appearance in improving Google searches to image recognition. Devices can now communicate with one another through what is called the Internet of Things (IoT). Although conservation may not adopt self-driving cars any time soon, the underlying technology is beginning to surface within the sector. AI has been used in such things as whale identification in images (Berger-Wolf *et al.*, 2017). This same technology has been used in conjunction with IoT to automatically identify and share wildlife images captured by remote trail cameras (Elias *et al.*, 2017). Drones, satellite imagery and big data analytics are also being utilised (Snaddon *et al.*, 2013; Pimm *et al.*, 2015; Marvin *et al.*, 2016). Embracing emerging technologies is becoming more common in conservation.

As new technologies begin to surface, conservation-based applications are explored. Arguably, the most exciting new technology to emerge in recent years is blockchain. Blockchain is a decentralised and distributed open ledger that records all transactions that occur within a network of peers. It was created to improve financial traceability and eliminate the need for banks by enabling peers to trade directly with one another using cryptocurrencies (digital, online currencies) (Nakamoto, n.d.). The conservation sector was quick to find a use for blockchain. World Wildlife Fund (WWF), in partnership with ConsenSys, TraSeable and Sea Quest Fiji Ltd, ignored the intended financial application and instead applied the underlying technology to trace tuna from extraction to consumer. This increases transparency of the tuna supply chain, ensuring tuna are caught in a legal and sustainable way (Visser and Hanich, 2017). Other suggested conservation blockchain applications focus on enabling conservation funds to be distributed directly from a donor to a conservation project (Baynham-Herd, 2017). The addition of blockchain-based smart contracts has potential to further expand conservation adoptability.

Smart contracts are essentially coded contracts that automate transactions, such as the transfer of funds or digital representations of physical objects, between peers. They enforce the terms of an agreement by automating the fulfilment of a conditions. Ultimately, smart contracts are used to increase efficiency by decreasing human involvement in transactions. Because they are stored

and executed on a blockchain, smart contracts increase transparency and traceability of transactions (Alharby and Van Moorsel, 2017). This technology has already made an appearance in the conservation literature. Chapron has suggested that smart contracts could be used in natural resource management, to incentivise positive conservation actions, to prove goal achievement and in the conditional release of conservation funds (2017). The suggested use of smart contracts to provide proof-of-goal-achievement sparked the idea that this technology may have the potential to attract conservation investment.

It has been suggested that mobilising private funds through investment opportunities may decrease the conservation financial deficit (Kaiser, 2015). A reduction in available government funds for conservation paired with increased habitat loss and population decline has left conservation underfunded by billions of US dollars (Kaiser, 2015). Although investment may present a possible solution to this problem, a return on investment (ROI) must be provided to appeal to investors. This may be financial, such as from profits generated by an ecotourism enterprise, or non-financial, such as by meeting conservation targets (i.e., increasing the global protected area system) (Stephenson *et al.*, 2018). The latter requires conservation projects to provide proof-of-goal-achievement as evidence for non-financial ROI. Smart contracts could potentially be used to automate the distribution of both financial and non-financial ROI in a cost-efficient, transparent manner. Although theoretically possible, smart contracts have not yet been deployed for this purpose in conservation.

This research therefore explores this feasibility by asking the question: Can smart contracts be used to attract conservation investment? The question was answered through exploratory research of smart contracts to understand what this technology can afford to conservation investment. A model smart contract was developed using Rewilding Europe's (RE) European Wildlife Bank (EWB) as a case study to further understand if smart contracts are fit-for-purpose to attract conservation investment. Ultimately, this dissertation follows the pattern of exploring how emerging technologies can be utilised within conservation, but with particular focus on its use to tackle the conservation financial crisis.

2. Literature Review, Research Aims & Background Information

2.1 The Conservation Financial Crisis

As is no surprise to conservationists, the sector is underfunded and securing funds is becoming increasingly difficult. It is estimated that between US \$76 and \$440 billion is required to fully fund conservation efforts per year (Kaiser, 2015). This uncertainty can be attributed to inaccuracies in spending reports (especially in developing countries) and because consensus on establishing how much funding is needed to achieve conservation goals has not been reached (Waldron *et al.*, 2013). In reality, only US \$50 billion per year is spent on conservation projects, falling short of the minimum estimated funding required to meet global conservation targets (Kaiser, 2015).

Traditionally, conservation projects depended on government funds, but the availability of this funding source has decreased due to global governmental decentralisation. This has required many conservation projects to rely on large NGO finance, such as from WWF and the Nature Conservancy (Emerton, Bishop and Thomas, 2006). This has increased competition for funding, meaning conservation projects must better justify actions to receive funds or attract alternate funding sources such as private capital from corporations, individual citizens and philanthropic organisations (Emerton, Bishop and Thomas, 2006).

Although a newer concept, mobilising private capital can provide a substantial source of project finance. About US \$23 billion of conservation funding between 2009 and 2013 came from private capital. Of this, US \$1.9 billion stemmed from private investment (NatureVest and EKO, 2014). Unlike grants and donations, investment require recipients to payback a percentage of the invested capital, known as ROI, which incentivises investors to financially support projects (Stephenson *et al.*, 2018). NatureVest reported in 2014 that impact investors (investors that accept a positive societal or environmental non-financial ROI in return for a decreased financial ROI) are ready to invest US \$5.6 billion in conservation by 2018 (NatureVest and EKO, 2014). Another estimate placed the rise in impact investment, specifically directed at NGOs, at US \$400 to \$1000 billion by 2020 (Schrötgens and Boenigk, 2017). It is therefore necessary for conservation projects to capture this potential major source of funding to meet targets and resolve the conservation financial crisis (Mccarthy *et al.*, 2012; Waldron *et al.*, 2013).

2.2 Attracting Investment with Frame Adjustment

Attracting investment will require: 1) a change in the way current conservation projects are framed and 2) proof of non-financial ROI. The first includes a shift away from the idea that nature can only generate an intrinsic value and towards one that promotes its capability to deliver financial returns (Kaiser, 2015). It also entails framing conservation as an “opportunity” rather than a crisis (pg 2, Baumann *et al.*, 2017). This will enable conservation projects to outline both the potential financial and non-financial ROI necessary for investment appeal.

Jepson and colleagues provide an example of this (2017). They have suggested that reframing protected areas as a spatial asset, which generates multiple values, can attract investment. They defined a natural asset as something that can be “...protected, managed and/or invested in to generate forms of value...” (pg 184, Jepson *et al.*, 2017). This value can be social, financial and ecological and can be captured by human society or the ecosystem. They conclude that natural assets can be invested in to increase and maintain the values that they generate. These values, therefore, can be presented as potential ROI.

Because the conservation sector has little opportunity to provide financial ROI, potential investments are classified as “high risk and low return” (pg. 54, Emerton, Bishop and Thomas, 2006). For this reason, conservation projects should focus on the potential non-financial ROI that they can provide. This can therefore attract impact and socially responsible investors: investors who support projects that provide a positive social or environmental impact despite the reduced financial ROI (Kaiser, 2015; Estapé-Dubreuil, Ashta and Hédou, 2016; Schrötgens and Boenigk, 2017). Conservation impact investment is defined as “investments intended to return principal or generate profit while also driving a positive impact on natural resources and ecosystems” (pg 9, NatureVest and EKO, 2014). Some examples include biodiversity enterprise funds, which fund enterprises that benefit conservation (Emerton, Bishop and Thomas, 2006), the Netherlands Green Investment Directive, which provides tax breaks for those investing in the environment (Emerton, Bishop and Thomas, 2006), and green bonds, which ensure payback with interest after a set number of years (Jepson *et al.*, 2017). Other conservation investment opportunities include projects that focus on sustainable resources or the preservation or restoration of ecosystem services (i.e., water filtration and soil fertility rejuvenation) (Baumann *et al.*, 2017). No matter the investment

opportunity, investment recipients will need to provide investors with proof of a non-financial ROI (Costa and Pesci, 2016).

2.3 Attracting Investment with Non-Financial ROI

Proof-of-goal-achievement can be shared with investors as a form of non-financial ROI. This is not only for the “feel good” aspect that many impact investors are motivated by (pg 190, Schueth, 2003), but is also important for businesses, many of whom report their investment impacts back to customers to prove their corporate social responsibility (Dillenburg *et al.*, 2003; Nilsson, 2008; Bilbao-Terol, Arenas-Parra and Cã Nal-Fernández, 2016). Increased investment interest in the Environmental, Social and Governance (ESG) goals and the Sustainable Development Goals (SDGs) has placed more pressure on reporting proof of non-financial ROI (Apostolakis *et al.*, 2018). Securing conservation investment therefore requires conservation investment recipients to accurately and consistently report non-financial ROI to investors (Combs, 2014; Baumann *et al.*, 2017; Jepson *et al.*, 2017).

Conservation goal achievement, however, is not always easily measured. To account for this problem, non-financial ROI should be measured in a scientifically sound way that is relevant to investors (Hockings *et al.*, 2006). Guidelines have already been developed to measure, quantify and report SDG progress (Network, 2015) and should be used to maintain reporting consistency. This may require using remote sensing and other technologies to automate measurements to ensure low-cost data capture and accurate, regular reporting (Baumann *et al.*, 2017). Conservation projects should therefore ensure proof-of-goal-achievement is reported in a consistent and accurate way to attract investment.

Due to the ambiguity that may accompany proof-of-goal-achievement, trust must be developed in conservation investor-investee relationships. Trust, which is defined in investment as “...a subjective belief about the likelihood that a potential trading partner will act honestly...”, is incredibly important for securing conservation investment (pg 1, Hellmann *et al.*, 2011). This is because “...trust affects believability of messages regarding actions that have an impact upon the environment...” (pg 217, Winter and Cvetkovich, 2010). Trust is particularly necessary in securing conservation investments that involve private landowners as information is less publically

available (Young *et al.*, 2016). In addition, NGO scandals, such as the 2002 Nature Conservancy financial scandal where the president's salary was not accurately reported, makes securing trust between NGOs and investors necessary (Stephens and Ottaway, 2003; Crack, 2013). Fortunately, trust can be built with increased information transparency (Shorish, 2017). Proof-of-goal-achievement must therefore be transparent to gain investor trust that non-financial ROI is truthfully reported.

Consistency, accuracy and transparency are key in providing proof of non-financial ROI. Traditionally, proof-of-goal-achievement is verified to be true through independent, third-party audits and certification schemes (Baumann *et al.*, 2017). Although these methods increase trust in conservation reporting, it comes at a financial cost. This can detract from an investment opportunity, as financial ROI is already limited or non-existent. Conservation projects must therefore find a low-cost proof-of-goal-achievement reporting method to secure conservation investment.

2.4 Attracting Investment with Smart Contracts

As outlined above, successfully attracting conservation investment requires a transparent, reliable and cost-effective system for non-financial ROI reporting. Smart contracts increase transparency by facilitating transactions in a low-cost, decentralised way (Watanabe *et al.*, 2016) and could therefore be explored for potential adoption for this purpose.

Smart contracts are essentially computer code that automate direct transactions between individuals and are stored and executed on a blockchain (Rozario and Vasarhelyi, 2018). A blockchain is an online decentralised ledger that maintains a chronological record of all transactions that occur within a network of peers (Magazzeni, McBurney and Nash, 2017). Transactions include the transfer of information and digital assets, such as funds or a digital representation of a physical object. Smart contracts could be used in the direct transfer of funds to conservation projects without the need for a bank (Baynham-Herd, 2017) or enable the transfer of a digital representation of a zoo animal to openly track ownership history. Because a blockchain is decentralised, every person connected to the blockchain network stores a copy of the ledger. This ensures all transactions are transparent, enables low-cost sharing of information and enables

users to verify that transactions are true. This eliminates the need for trust in investor-investee relationships because information can be shared directly from the data capture source without human interference. Further, the transparency and multiple ledger copies ensures that data cannot be manipulated once shared on a blockchain. Ultimately, smart contracts automate processes in a transparent and cost-effective way.

Because smart contracts have become popular in the finance and technology industries (Subramanian, 2018), it is not surprising that it has appeared in the conservation literature. Chapron has suggested smart contracts be used to ensure proof-of-certification, in natural resource and supply-chain management, and to incentivise positive conservation impact through the distribution of funds upon proof-of-goal-achievement (2017). However, its specific use for the purpose of attracting conservation investment in response to the conservation financial crisis has not yet been suggested.

2.5 Research Questions & Purpose

This dissertation proposed that smart contracts could be used to attract conservation investment. Due to a lack in conservation-specific smart contract literature, however, the affordance to conservation at a broader level was identified as a necessary research component. The purpose of this research, therefore, was to answer the following questions:

- What can smart contracts afford to conservation?
 - What are the technological possibilities and limitations of smart contracts?
 - How can conservation tools and technologies be integrated with smart contracts?
 - How are smart contracts currently used in conservation?
 - In what ways could smart contracts potentially be used in conservation?
- How can smart contracts be used to attract conservation investment?
 - What does a model smart contract look like in conservation investment?

The intended impact of this research was to determine if smart contracts could be implemented to attract investment as a solution to the conservation financial crisis. On a broader scale, however, it aimed to increase knowledge of smart contract technology within the conservation sector and

spark further discussion of its use. EWB was used as a case study to illustrate how smart contracts could be used in a real-world conservation project scenario.

2.6 EWB Background Information

EWB is one of RE's initiatives to restore European landscapes through rewilding. Rewilding is the process of restoring ecosystem functions through the reintroduction of wildlife (Pires, 2017). According to insights revealed during EWB interviews, EWB accomplishes this through the facilitation of animal herd loans comprising ibex, European bison, wild horse species and cow breeds belonging to the Taurus Foundation. EWB loans enable partners (NGOs, land managers and some farmers in 30 areas across Europe) to manage a herd for a set period of time, after which 50% of the herd must be returned to EWB. For example, if an initial herd loan of 100 animals grew to 280 at the end of a 5-year loan, 140 animals are returned to EWB. Partners also have the option to extend the loan at the end of a loan period if the area of land reserved for grazing is increased. More detailed information regarding EWB goals and operations can be found in Appendix 1. This information was used along with details gathered from exploratory smart contract research to develop a smart contract model specifically designed to attract EWB investment.

3. Methods

I took a two-step approach to answer the overarching question of this dissertation: the Exploratory Research Phase and the Model Development Phase. I first conducted exploratory research to gain insights into the technological possibilities and limitations of smart contracts and their current use in conservation. I used this information in the second phase of this dissertation to build a model smart contract using EWB as a case study. This further revealed opportunities, constraints and additional research needs for implementing smart contracts to attract conservation investment. Figure 3.1 visualises the method followed to develop the final smart contract model.

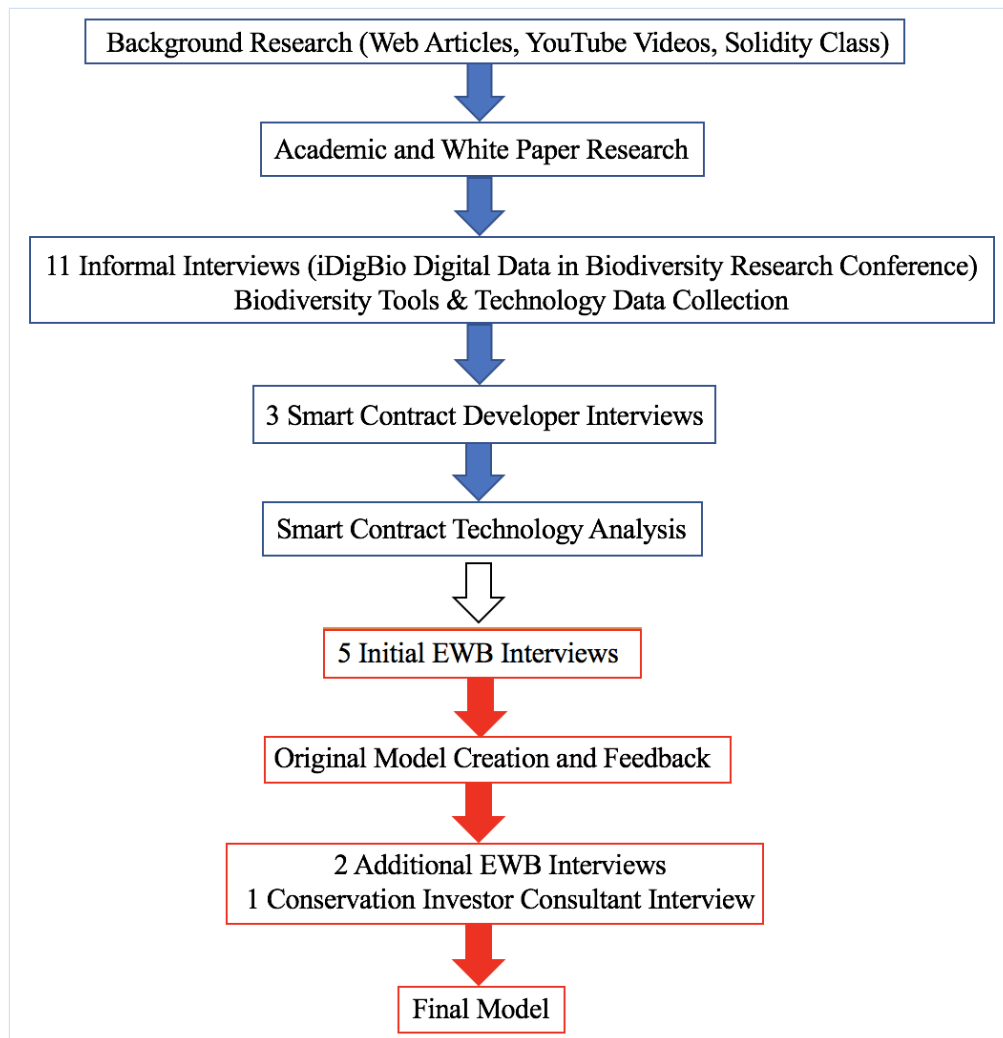


Figure 3.1: Method visualisation: Blue indicates the Exploratory Research Phase; Red indicates the Model Development Phase.

3.1 Exploratory Research Phase

The Exploratory Research Phase included performing background research, consulting papers that detailed smart contract technology, gathering a list of conservation tools for integration analysis and conducting interviews.

As smart contracts and blockchain research is in its infancy, peer reviewed research was difficult to find. As such, I conducted background research prior to gathering academic and white papers. This involved consultation of non-academic articles and YouTube videos (Appendix 2). I also took a Solidity smart contract coding language class taught by the Oxford Blockchain Society at the Oxford Foundry from January until March 2018. This provided initial understanding of technical terms of smart contracts.

Background research enabled analyses of blockchain and smart contract academic papers. Academic papers are defined as those that have been peer reviewed and papers presented at academic conferences. I compiled and analysed 44 papers for mention of blockchain features, smart contract features, stated limitations, new technological contributions, and suggested future directions of research. A full list of academic papers consulted and the search terms used to identify them can be found in Appendix 3.

There was a limited number of current academic papers describing technical parameters and current use cases; thus, I consulted 112 white papers to reveal further insights into smart contract technical details and current conservation use cases. White papers are published by businesses to detail the technology of a product (BusinessDictionary.com, n.d.). They increased certainty of potential conservation uses and confirmed that the developed model was technically possible. Technical details, new technical contributions and the applicability to conservation were assessed. A full list of white papers consulted and the terms used to collect these papers can be found in Appendix 4.

To better understand how smart contracts could be adopted in conservation practice, a list of 126 conservation tools and technologies was compiled and analysed for potential integration (Appendix 5). I gathered this list based on personal experience, presentations in the Technology Empowered Conservation Series presented at the University of Oxford between January and

March 2018, searching Google for “conservation tools” and from presentations at the iDigBio Digital Data in Biodiversity Research Conference held at the University of California, Berkeley between June 4th and June 6th, 2018 (here on out referred to as “Conference”). Each tool was placed in a classification group (Data Analysis, Data Capture, Fund Raising & Funding Flow, Information Platforms & Open Databases, Internal Data Storage & Management, Monitoring & Tracking, Report Generation and Prediction). Current and potential integration with smart contracts was analysed for each group based on the academic and white paper analysis and insights gained during smart contract developer interviews (explained below).

Questions raised regarding conservation tool integration and technological limitations was compiled as interview questions directed at smart contract developers. I also informally interviewed attendees of the Conference, EWB employees and a conservation investment consultant. Details of these interviews are outlined below.

3.2 Interviews

I conducted 4 sets of interviews: Conference attendees, smart contract developers, EWB employees and conservation investment consultancy.

I informally interviewed 11 individuals of the 229 registered attendees of the Conference. Interviews were not recorded. I spoke to a marine biology student and employees of natural history museums and universities, environmental and biodiversity data aggregate, biodiversity technology companies, an environmental research funding body, NASA and Google Earth Engine (GEE). I asked participants about their knowledge of blockchain and smart contracts and if they personally used or knew of projects that used smart contracts within the field of conservation. This information gave me an initial sense of smart contract use and understanding within the field.

For formal data collection, I conducted 11 semi-structured key informant interviews. Appendix 6 lists the sets of questions developed for the remaining interview groups. I chose key informants to provide the most detailed and knowledgeable insights into smart contract technology, the EWB programme and conservation investing. All interviews were recorded using GarageBand software and transcribed directly into a Word document. I chose this method over NVivo based on my

familiarity with the software and because interview results did not require coding for analysis. I used Skype or Zoom (interviewee preference) for all remote interviews.

Smart contract key informants were defined as those who work as smart contract developers for notable smart contract development companies. I identified 18 leading smart contract developer companies and platforms by searching recent and upcoming blockchain and smart contract conference speaker lists, a smart contract developer award nomination list and companies mentioned often in informal articles and YouTube videos (Appendix 7). I contacted smart contract developers via email using addresses available on company websites that directed to press, developer, human resource, or help/information departments. I secured 3 interviews and asked questions aimed to explore conservation-specific technical components of smart contracts not explicitly outlined in the academic literature. I also asked less technical questions to provide insight into current and potential future smart contract use within conservation. Specific questions can be found in Appendix 6.

Technical knowledge gained from smart contract developer interviews was combined with EWB programme insights to create a conservation-specific model smart contract. I used snowball sampling to secure 7 EWB interviews. My advisor connected me with a RE employee with knowledge of EWB who then identified key informants based on their expertise on EWB's function and goals. Of the 5 individuals initially contacted, 4 interviews were secured. I conducted 1 interview in person at the RE office in Nijmegen, The Netherlands while all others were conducted remotely. I then interviewed an individual identified to have key insights into the EWB herd loan process and 2 herd managers to gain an additional insight into EWB activities (1 via Skype, 1 via email response). All interview questions were designed to provide insight into EWB's goals, specifically how they are measured and reported. Each question focused on the tools and technology used in each activity. Questions were also asked regarding current limitations in these methods and areas identified in need of improvement. Appendix 6 lists the specific questions asked.

To further complete the model, I interviewed a conservation investment consultant. My advisor identified 3 key informants who could provide insight into conservation investment. I secured one interview and asked questions to gain insight into what guides investor decisions, what information

is needed to feel as though non-financial ROI has been received and regarding non-financial ROI management systems. Specific questions are listed in Appendix 6.

For all formal interviews, ethics and good practice were guided by the Association of American Geographers Statement on Professional Ethics and the University of Oxford's online Research Integrity for Social and Behavioural Sciences course. Interview audio was recorded and interviewees were pseudonymised by saving audio and transcription files with a code only known to the researcher. Contact information and the code identifier were securely encrypted and saved on a personal password-protected laptop. All interviewees were over 18 years of age and provided written and verbal consent to be interviewed and for the audio to be recorded. Participants had the option for the audio file to be destroyed immediately after transcription. Audio and transcription files will be retained until publication of the research or within three years, whichever is soonest. No direct quotations were used in this dissertation. All participants had the right to remove their interview responses from the study until August 13th.

3.3 Model Development Phase

Technological insights gained during the exploratory research phase provided the basis for developing the smart contract model. EWB was used as a case study to illustrate a real-world smart contract application for investment attraction. EWB was chosen for its multi-step processes, expressed desire to attract investment and interest in incorporating blockchain technology within the project. EWB has potential to provide both financial and non-financial ROI based on such things as their eventual plan to sell herd animals for meat consumption and their clear landscape rejuvenation goals.

Interviews revealed details of project operations, which I used in the creation of the model smart contract. Interviews also revealed areas identified for EWB improvement. Full EWB operational details and identified areas of improvement can be found in Appendix 1. I determined if smart contracts could be used to address each of these improvements. The original models developed aimed to attract investment while also improving EWB operations.

These original models were shared with the four initial EWB interviewees to identify areas for improvement or to comment on additional limitations not spoken of during interviews (Appendix 8). One interviewee provided feedback, which was used to refine the models.

I created the final model based on the feedback received and further information gathered from the additional EWB interviews and the conservation investment consultant interview. The EWB loan contract management interviewee placed emphasis on a need for data connectivity while herd manager interviews revealed more specific insights into data collection and reporting methods. This information, along with a list of 40 indicators EWB uses to report to donors on goal achievement progress (van de Vlasakker, 2014), was used to create two specific smart contract examples to best illustrate proof-of-goal-achievement. I used information gathered from the investment consultant interview to further refine the model to appeal to investor wants and needs.

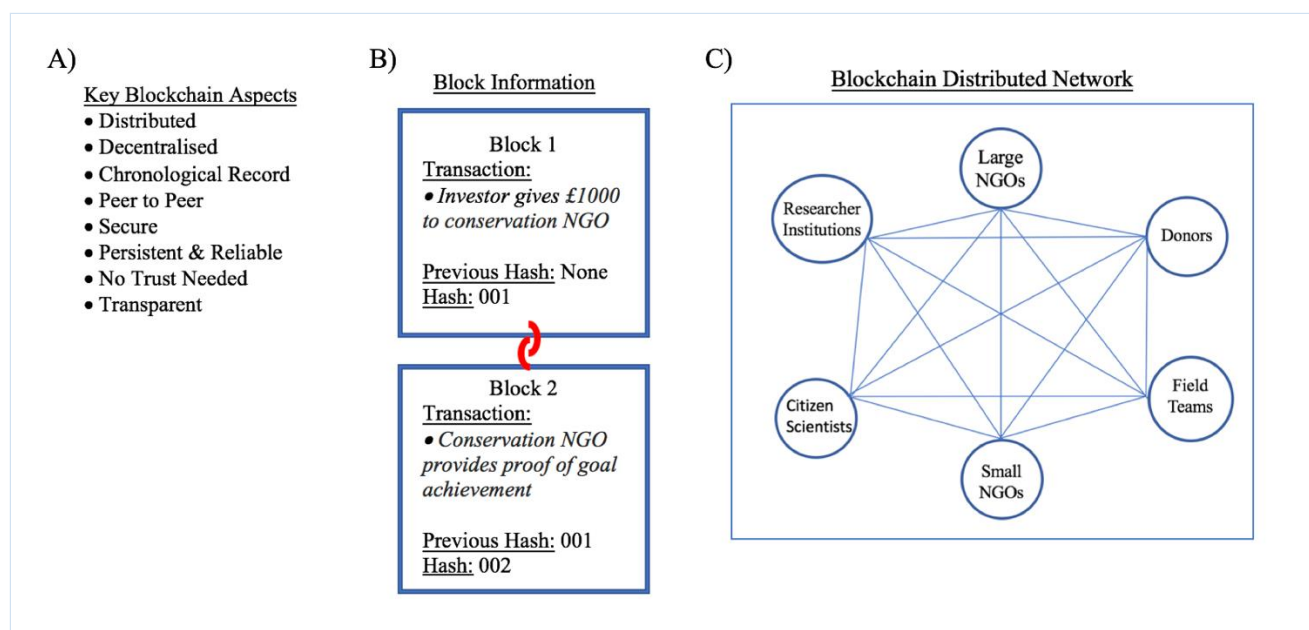
The final model was written using a modified Attributes, Deontic, aIm, Conditions, Or else (ADICO) format (Frantz and Nowostawski, 2016). This format is more understandable than smart contract code. Frantz and Nowostawski created this format to break down an intended smart contract to identify actors (A), their obligations (D), the intended action (I), the conditions in which this must take place (C) and the consequences that occur if the conditions are not met (O) (2017). The target, or where the action is directed, is also included where applicable. Nested ADICO enable AND statements which can enable further action related to a prior action. If no C is specified, the action must occur under any circumstance and if no O is specified, no consequence occurs if the condition is not fulfilled. The models presented in this paper have modified the ADICO format to best aid understanding of the smart contract process by replacing some specific coding terms with plain language.

I used the final model to identify opportunities and restrictions in current adoption of smart contracts by conservation projects. This focused on tool integration requirements and ultimately revealed how fit for purpose smart contracts are to attract conservation investment.

4. Smart Contract Affordance to Conservation

4.1 Smart Contract Possibilities and Limitations

Detailing possibilities and limitations requires understanding technical aspects of smart contracts. Smart contracts are stored and executed on a blockchain (Idelberger *et al.*, 2016). Blockchain, also known as Decentralised Ledger Technology, was created by Satoshi Nakamoto with the invention of the cryptocurrency Bitcoin, a digital currency that is not state-issued and requires no centralised bank (Nakamoto, n.d.). Blockchains are most generally used in the transfer of cryptocurrencies for online and real-world purchases, to maintain proof that something exists, provide digital signatures, ensure voting rules are followed and to track ownership change with the use of a digital representation of a file or object (Underwood, 2016; Xu *et al.*, 2016). Blockchains are a chronological record of every transaction that occurs in a network of peers. A transaction can be the transfer of a cryptocurrency or information, such as proof that a conservation goal has been reached. Each peer, also known as a node, stores a copy of the blockchain. Each transaction is shared with the network, and every copy of a blockchain is updated to include the transaction. Because of this, blockchains are decentralised and distributed, meaning no one individual has control of a blockchain. This cuts out third parties and enables peers to transact directly with one another, such as a donor providing funds directly to an on-the-ground conservation project without the need for a bank or large NGO to distribute funds. Decentralisation also increases security because altering a transaction already on a blockchain would require changing every copy in the network. Nodes can validate a blockchain to be true based on their own copy, enabling peers to identify falsified transactions. Blockchains are immune to hacking, security breaches and single-point failures (when information is lost when a server fails). Blockchains are therefore durable, persistent and reliable. These aspects eliminate the need for trust between peers as all transactions are fully transparent (Underwood, 2016; Xu *et al.*, 2016; Ahram *et al.*, 2017). Box 1 outlines key blockchain aspects, depicts an example of the type of information found in a block on a blockchain and shows the connections between each node in a blockchain network.



Box 1: A summary of blockchain information: A) lists key blockchain aspects; B) depicts the type of information that may be found on blocks in a blockchain. This includes details of the transaction and a block identification number, known as a “hash”, that contains information regarding the transaction. Each block also contains the hash of the prior block, creating the blockchain. The first block will not contain this as it is the origin block in a blockchain; C) is an example of a potential conservation-specific blockchain network. Each node owns a copy of the blockchain and there is no one central node in charge. Each node is equally connected to one another.

A blockchain is made of multiple blocks linked together in chronological order. Each block represents a group of transactions. Every block contains transaction information, as well as other such things as a unique identification, known as a hash, and the prior block’s hash. This enables blocks to be linked to one another, creating a chain. Each hash is unique and created using the information within a block. If a block is changed, the hash will also change. This will be easily caught by network peers because the following block will no longer contain a hash to link it to the prior block. This function creates a secure ledger of ordered transactions (Imbault *et al.*, 2017; Li *et al.*, 2017).

Table 4.1: Differences between limited and open access blockchains

Limited Access Blockchain	Open Access Blockchain
Permissioned	Permissionless
Private	Public
Closed	Open
Smaller Network	Larger Network
Faster Transaction Speeds	Slower Transaction Speeds
Restricted Access	No Restrictions
More Centralised	Fully Decentralised
More Trust Required	No Trust Required
Lower Computational Cost	Higher Computational Cost
Less Anonymity	More Anonymity

Although the connectivity is the same, different blockchains can serve different functions. Table 4.1 describes the different blockchain types: limited access and open access. Limited access blockchains, sometimes referred to as permissioned, private and closed, restrict access to the network. This type of blockchain is useful for networks that wish to maintain a level of privacy regarding their transactions, such as restricting knowledge of the exact location of an endangered species population. Limited access blockchains are generally smaller with a fewer number of peers who own a copy of the blockchain. Although this increases the speed of transactions and lowers computational cost of storing a blockchain, it also introduces the need for trust because rules regarding who can join the network become centralised (Xu *et al.*, 2016; Ølnes, Ubacht and Janssen, 2017). Open access blockchains, also known as permissionless, public and open, enable anyone to view and participate in transactions. This type of blockchain is commonly used in networks that do not share sensitive material or those that focus primarily on the exchange of funds. For example, they might be used in the direct transfer of conservation funds from donors to conservation projects. Although open access blockchains have no restrictions and take on all blockchain benefits, a larger network of peers requires higher computational costs and slower transaction speeds (Ølnes, Ubacht and Janssen, 2017). Hybrid blockchains take aspects of each blockchain type and are created to suit a specific network’s needs, such as a potential conservation network where the public could view transactions but only specified conservation-related node with permission could participate in the transfer of information (Smart Contract Developer, Interview, 2018). The type of blockchain that could be implemented for conservation purposes is

therefore project-specific. As learned thus far, blockchains are essentially an online, secure record of transactions with customisable access.

The most common use for blockchain stems back to its original purpose: to eliminate the need for banks with the creation of online, digital cryptocurrencies. Although the original cryptocurrency (Bitcoin) is most notable, other cryptocurrencies include Ether, Dash, Ripple and Tether (Khan and Salah, 2018). Each cryptocurrency operates on its own blockchain and can be used for different services, but existing platforms can facilitate the exchange between different cryptocurrencies and fiat (traditional, government-issued money) (JOYSO, 2018). Cryptocurrencies are fungible tokens, enabling division into smaller components and each token equally represents the currency (Omohundro, 2014). This means cryptocurrencies operate like US dollars where a single dollar can be divided into smaller amount and each 50-cent piece is worth an identical amount. Cryptocurrencies became popular because cutting out the need for a bank enables direct payment without delay and decreases financial fees associated with transactions. They also eliminate the double-spending problem. This is where an individual spends more money than they actually have, ultimately leaving a product or service provider without payment. Cryptocurrencies solve this problem because transactions will only occur if an individual's digital, online wallet contains enough funds. The transaction history on a blockchain is used to confirm this (Nofer *et al.*, 2017). In addition to cryptocurrencies, non-fungible tokens can exist on a blockchain. These are unique, digital representations of such things as a certificate or an individual animal. Unlike fungible tokens, non-fungible tokens cannot be divided into a smaller amount and have unequal worth (CryptoKitties Team, 2017). For instance, a non-fungible token representing a tiger in a zoo cannot be divided into multiple parts as the transfer of a tiger involves the entire individual to be moved, and not just part of it. Additionally, two individual tigers are not identical. Non-fungible tokens can be useful because they can be used to trace ownership of an object (CryptoKitties Team, 2017). Blockchains can therefore be applied in a financial context or to increase traceability and improve ownership transparency.

Smart contracts extend the function of blockchains. The concept of smart contracts was first presented in 1997 by Nick Szabo. Szabo compared a smart contract to a vending machine where an item is only dispensed when the correct funds are entered into the machine. He describes the technology as a programme that proves performance, enforces commitment, and verifies that

actions take place without the use of a third party (Szabo, 1997). Vitalik Buterin, the Ethereum blockchain network creator, first combined smart contracts with blockchain in 2013 (Buterin, 2014). In the blockchain context, smart contracts are essentially a set of “multi-step processes” written in code that automates transactions (pg 15., Ahmad, 2017). They are written in “if, then, else” statements, meaning if a condition is met, then the programme will do X, otherwise it will do Y (Cuccuru, 2017). For example, if a conservation project proves a goal has been met, then a donor will provide funds, else the donor will not provide funds. Essentially, any action that can be programmed and controlled by a computer can be written into smart contract code (Luu *et al.*, 2016).

Smart contracts are executed and stored on a blockchain. This means that a smart contract code is part of a block on a blockchain. The smart contract carries out the coded programme once triggered by a user in the network or a predetermined condition, such as a specific date. The outcomes of the smart contract are also recorded in a block on the blockchain (Ahmad, 2017). Because smart contract code is stored and executed on a blockchain, they inherit all the benefits of blockchain technology. Smart contracts are transparent and verifiable, but can also be private (Abdellatif and Brousmiche, 2018). They are efficient, low cost and decrease human involvement and the need for trust (Idelberger *et al.*, 2016; Giancaspro, 2017). Because they are stored on a blockchain, which are resistant to single-point failures, smart contracts will execute even in the event a node in the network fails (Li *et al.*, 2017). Manipulation or unauthorised changes to a smart contract can be easily spotted as each node in the network owns a copy of the code (Egelund-Müller *et al.*, 2017). Smart contracts enforce agreements, hold all transaction parties accountable and ensures the agreement is interpreted in the same way, eliminating misinterpretations (Abdellatif and Brousmiche, 2018). Box 2 lists these key smart contract aspects.

A)

Key Smart Contract Aspects

- Computer Code
- Automated Transactions
- Proof of Performance
- Enforce Agreements
- Stored & Executed on a Blockchain
- Only Act When Triggered
- Transactions are Conditional
- Written Using “If, Then, Else” Statements

B)

Smart Contract Limitations

- Cannot Transfer Fiat
- Cannot Store Files
- Must Rely on Oracles for Outside Data
- Inflexible, Unchangeable, Irreversible
- Can Be Computationally Expensive
- Complicated Language

Box 2: Smart Contract Overview: A) lists the key smart contract aspects; B) lists some of the limitations of smart contract technology.

Smart contracts are described as passive, meaning they only operate when triggered (Egelund-Müller *et al.*, 2017). Nodes in the network, a pre-specified event such as a specific date, and even other smart contracts can trigger a smart contract to execute the coded programme (Sklaroff, 2017). Each smart contract has a unique address by which it can be triggered by a node in the network (Luu *et al.*, 2016; Alharby and Van Moorsel, 2017). Once enacted, each node in the network executes the code. The results of each copy of the code executed will need to be identical to validate the smart contract’s outcome, enabling users to trust that the smart contract’s output is reliable and true (Alharby and Van Moorsel, 2017; Levy, 2017). For example, if each smart contract returned the same percent of forest growth between two dates, nodes in the network can be sure the percentage is true. Smart contracts therefore enable automation while eliminating the need for trust in transaction outcomes.

Although smart contracts enable many different transactions to be automated and triggered by various means, some limitations restrict their potential conservation-related use. Box 2 lists some of these limitations. The main restrictions of this technology centre around inflexibility and complexity, the inability to store files, incapability to connect to data and the restriction of traditional currencies (Ahmad, 2017; Hazard and Haapio, 2017; Smart Contract Developer, Interview, 2018). Solutions to these issues have already been realised by smart contract companies,

but may still present implementation feasibility issues for conservation. A full list of limitations and solutions can be found in Appendix 10. The key limitations and solutions are detailed below.

Smart contract language complexity and inflexibility present a problem for easy conservation adoption. Smart contract coding language is foreign to those with limited coding ability (Magazzeni, McBurney and Nash, 2017). This can lead to coding errors (Luu *et al.*, 2016; Mik, 2017). Smart contracts cannot be reversed and are difficult to stop once deployed. Further, smart contracts are inflexible, meaning all future possible conditions must be coded prior to deployment (Mik, 2017). This may make smart contracts more expensive than traditional contracts or automated processes (Sklaroff, 2017). Some solutions include smart contract templates, algorithms that translate natural language to code, and functions that can stop a smart contract once an error has been noticed (Nugent, Upton and Cimpoesu, 2016; Smart Contract Developer, Interview, 2018). Some networks also enable smart contract testing prior to deployment (Smart Contract Developer, Interview, 2018). Although some solutions, such as user-friendly interfaces ease this problem (Benet and Ai, 2017), smart contract use may require conservationists to increase coding knowledge, seek partnerships with smart contract developers or pay for existing solutions to this problem.

Although conservation projects could pay for services to eliminate the complexity problem outlined above, this would require conservationists to hold cryptocurrencies. Smart contracts are unable to transfer fiat (traditional government-dispersed currencies such as euros, UK pounds and US dollars). Fiat cannot be transferred using smart contracts because the ledger is used to keep track of account balances. This would require every bank to put their ledgers on a blockchain, something that may occur in the future, but is currently not in operation (Smart Contract Developer, Interview, 2018). Holding cryptocurrencies presents issue for conservationist projects as cryptocurrencies are more volatile than fiat (Lee, Guo and Wang, 2018). Holding a cryptocurrency can therefore be seen as bad business and illegitimate for NGOs to engage in as already limited conservation funds could be at risk in the case of a cryptocurrency crash (Conservation Investment Consultant, Interview, 2018). Solutions to this include using a cryptocurrency that maintains a 1 to 1 fiat exchange rate, such as Tether, or automating the exchange from a fiat to a cryptocurrency on a conservation platform (Lukacs and Bhadra, 2012; Virtua, n.d.). Although enabling fiat transfer with smart contracts is currently in the works (Smart

Contract Developer, Interview, 2018), conservation projects will need to engage with cryptocurrencies when adopting current smart contract technology.

Additional limitations are revealed when we recall that smart contracts are solely programmes and blockchains are essentially a list of transactions. This first involves a blockchain's limited file storage abilities. This means storing files and large amount of data on a blockchain is computationally expensive and inefficient (Xu *et al.*, 2016). To avoid the high computational cost of storing files on a blockchain or using smart contracts to share files, a smart contract can be used to enable individuals in a network to access a file. This can be done in ways such as placing a file in a decentralised file storage system (i.e., Storj) and listing a file identification number in a blockchain or encrypting a file and using a smart contract to transfer encryption keys to select individuals (Wilkinson *et al.*, 2014). Although this solution enables indirect file transfer, it complicates the file sharing process and requires a cryptocurrency payment. This limits the benefits that smart contracts can offer to conservation.

The second, and most notable, limitation is that smart contracts are simple programmes that do not possess the ability to pull data from outside of a blockchain. The inability for smart contracts to connect to this “outside world data” can severely limit the potential uses for conservation. A solution to this problem is to engage an oracle service. Oracle services connect to data providers to trigger or provide information to a smart contract (Xu *et al.*, 2016; Alharby and Van Moorsel, 2017; Sergey and Hobor, 2017). Oraclize is a company that runs an oracle service, facilitating the communication between smart contracts and outside world data. For instance, written into the smart contract code will be a call function to Oraclize. This connection will occur when the smart contract is triggered by a node in the network, usually through the transfer of a cryptocurrency to Oraclize. Oraclize will then monitor a data provider, such as an online database or an IoT-enabled device, for the specified data noted in the smart contract. Once the specified data has been found, such as a specific date, Oraclize will return this information to the smart contract (Sergey and Hobor, 2017). Alternatively, an oracle service could send this data to another online platform, such as GEE or Wolfram Alpha, to analyse the data and return a simple figure, such as a percentage, to the smart contract (Smart Contract Developer, Interview, 2018). Oracle services can connect to any accessible data feed, such as online platforms with open APIs (Smart Contract Developer, Interview, 2018). Figure 4.1 visualises the oracle service role in providing data to smart contracts.

Although oracle services enable more potential conservation applications, their use is restricted to data that can be accessed remotely. These tools and technologies are explored in the following section.

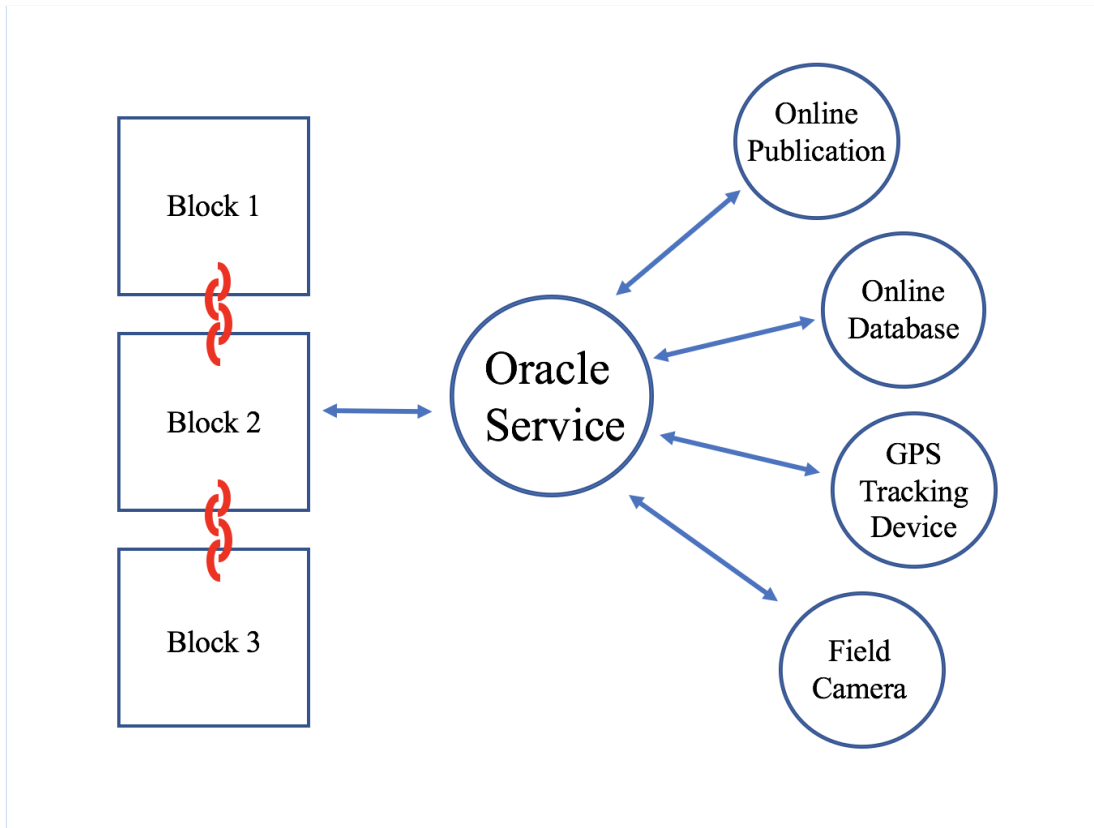


Figure 4.1: Overview of Oracle Service: depiction of how an oracle service is used to grab data and information from an “outside world” data provider to return to a smart contract on a blockchain. This example uses an online publication, which could return a TRUE/FALSE value based on if a study has been published or not, and an online database, which could return a TRUE/FALSE value if a dataset has been published or simple values such as a percentage. It also depicts connection to both a GPS tracking device and a field camera which can return GPS coordinates and images, but only if these devices enable remote connection.

4.2 Conservation Tool Integration

An oracle service is required for conservation tool integration with smart contracts. A summary of the integration of the 8 tool groups identified is outlined in Table 4.2. Based on the technological possibilities of smart contracts revealed in interviews, academic and white papers, some tools in

the Fund Raising and Funding Flow category have potential to be replaced by smart contracts, 3 tool categories cannot be integrated and 4 categories have potential to be integrated with smart contracts.

The Fund Raising and Funding Flow category includes crowd funding tools such as Kickstarter. This was identified as having potential to be replaced by smart contracts. This is due to already existing smart contract applications that enable decentralised crowdfunding (Popov *et al.*, 2016). Smart contracts have also been used in the direct distribution of donations (Benet and Ai, 2017). Additional financial smart contract uses are expanded upon in section 4.4.

The three categories that lack integration capability include Internal Data Storage & Management, Report Generation and Prediction. Internal Data Storage & Management tool are generally not cloud-based and therefore cannot be accessed by an oracle service. A tool in this category that is cloud-based could potentially be integrated, but only if an oracle service is granted access to the data. This would however require access information to be shared on the blockchain, enabling all nodes in the network to potentially gain access. Report Generation tools are generally internal and not remote accessible. Some tools in this category, such as Oxford's Local Ecological Footprinting Tool, are web-based and could potentially be integrated with smart contracts. The evidence is unclear, however, and further research is required to determine the technological possibilities and requirements of this. Prediction tools include artificial intelligence and agent-based modelling. No real purpose for prediction tool integration was identified. This result is not surprising as oracle services can only utilise tools with remote access.

The tool groups that offer potential smart contract integration include: Information Platforms & Open Databases, Monitoring & Tracking Tools, Data Capture Tools and Data Analysis Tools. Information Platforms & Open Databases have the simplest integration capabilities as these information sources are readily available online. Tools that fall into this category include Global Biodiversity Information Facility (GBIF), natural history museum databases and Global Forest Watch. Smart contracts could be used to confirm the existence of a dataset, locate a museum specimen or trigger project steps based on information regarding forest intactness. Monitoring & tracking tools, such as Global Positioning System (GPS) tracking collars, also have great potential to provide information to smart contracts as they already send data to an online source. Oracle

services might return GPS coordinates of a tracked individual at a pre-specified date to a smart contract. Data capture tools can only be integrated with smart contracts if they are IoT-enabled or if the data is automatically shared to an online database. Data capture tools with these capabilities include tablet-based field data collection applications that share data directly to an online database. An oracle service could monitor such an application to prove that data has been collected or return specific information to a smart contract (i.e., population counts). Iot-enabled trail cameras also fall under this category. An oracle service could be used to extract images from the camera and share them directly to an image-hosting site, such as Flickr. Drones, which can be used to collect images and videos, have already been integrated with smart contracts (Aero, 2017). Data analysis tools can only be utilised if they are online. These include such things as GEE and Zooniverse. An oracle service could extract data from one of the previously mentioned data sources and send it to an online data analysis platform. Although it has yet to be utilised with smart contracts (Conference Attendee, Informal Interview, 2018), GEE could be utilised to automatically analyse satellite images between dates to return such things as percent land change over time (Smart Contract Developer, Interview, 2018). For a simpler use, an oracle service could monitor the crowdsourced image identification tool, Zooniverse, to monitor percent completion of a project. This could be used to satisfy a smart contract condition to trigger the next step in a project. The current and potential integration of these tools is explored in sections 4.3 and 4.4.

Table 4.2: Conservation tools and technology groups and their potential incorporation with smart contracts. Sources include smart contract developer interview data and white papers that outlined use of similar technologies. A list of tools that fall into each category can be found in Appendix 5.

Tool Group	Possible Smart Contracts Integration	Sources
Data Analysis	Integration possible only with online analysis platforms	(Xu et al., 2016; Smart Contract Developer, Interview, 2018)
Data Capture	Integration possible only with remote accessible devices	(Xu et al., 2016)
Fund Raising & Funding Flow	No integration possible; potential to replace some tools with smart contracts	(Xu et al., 2016; FriendsFingers., n.d.)
Information Platforms & Open Databases	Integration easily possible with open APIs; permission needed for integration of tools with closed APIs	(Xu et al., 2016; Smart Contract Developer, Interview, 2018)
Internal Data Storage & Management	No integration possible unless management system is cloud-based	(Xu et al., 2016)
Monitoring & Tracking	Integration possible for tools with remote accessible data	(Seifert, 2017; Trouw, Levin and Scheper, 2018; Wolberger, Lionel; Mason, Allon; Capkun, 2018)
Report Generation	No integration possible	(Xu et al., 2016)
Prediction	No integration possible	(Xu et al., 2016)

4.3 Current Use in Conservation

Exploratory research revealed 11 current conservation-specific smart contract applications. Of the 9 plenary sessions, 54 oral presentations, 24 posters, and 11 discussion sessions at the Conference, none presented information regarding blockchain or smart contracts. Only two professionals of the 11 attendees spoken to were knowledgeable of blockchain and smart contracts, only 1 of which had considered its use in conservation, focusing on its potential use in natural history museum specimen databases. The white paper data combined with information gathered from smart contract developer interviews, personal communication with colleagues knowledgeable of the subject and web and YouTube searches, however, revealed the 11 conservation-related smart contract applications (Table 4.3).

Currently, smart contracts are used in both financial and non-financial conservation applications. Financial uses include attracting funds through the sale of a digital collectible (CryptoKitties) and the distribution of funds to conservation projects (GainForest; Porini Foundation; Regen Network). Smart contracts have also been used to incentivise individuals to create a positive impact in return for a financial reward or an exchangeable token (bioBIT Network; GainForest; Plastic Bank; Porini Foundation; Regen Network). These applications utilise smart contracts to provide proof-of-goal-achievement. Nonfinancial current uses focus on offsetting (Poseidon; Veridium) and proving the sustainable and lawful extraction of resources (Bureau Veritas Groups; Provenance; Traseable). The conservation tool categories integrated with current conservation-related smart contracts include: Information Platforms & Open Databases (GBIF and iNaturalist used by bioBIT Network; satellite imagery used by GainForest and Regen Network), Monitoring & Tracking (Quick Response codes and Radio-frequency Identification tags used by Bureau Veritas Groups, Provenance and Traseable) and Data Capture (drones used by Regen Network; Global Information System used by Regen Network; IoT-enabled sensors used by Provenance and Regen Network). The 11 companies identified indicate the feasible implementation of conservation-specific smart contracts. This information is expanded upon in the next section to explore additional potential smart contract uses for conservation.

Table 4.3: Current conservation-specific smart contract applications

Company	Description	Source
bioBIT Network	Incentivizes citizen science through token distribution upon goal achievement such as species identification	(Hilsberg <i>et al.</i> , 2016)
Bureau Veritas Groups	QR codes are used to scan fish at each step of the supply chain to increase traceability and transparency	(BureauVeritasGroup, 2016)
CryptoKitties	In partnership with Ocean Elders and ACTAI Global, Honu is a digital non-fungible token which was auctioned to support sea turtle protection by funding Operation Jairo, Sea Shepherd Conservation Society in Antigua and Barbuda and Unite BVI's Saving the Turtles project	(Honu, 2018)
GainForest	GainForest distributes donor funds to Amazon rainforest conservation projects and provides proof of conservation to donors; project managers put a financial stake on land which is lost if the forest is not still protected after a set time, but is refunded with an additional reward if it still stands	(Gainforest.org, 2018)
Porini Foundation	The Green List Standard (GLS) Token is a cryptocurrency to be used with the IUCN's Green List to record progress towards and incentivize achievement of the IUCN's Green List Standard	(Eyholzer et al., n.d.)
Plastic Bank	Enables exchange of plastic items for tokens to incentivize plastic waste collection for recycling purposes; includes a verification system that ensures that purchased plastic has been recycled	(Plastic Bank, 2018)
Poseidon	OCEAN tokens are used in carbon offsetting	(Poseidon, 2018)
Provenance	Location of tuna capture, movement of product, and such things as the temperature in which the fish was stored during transit are recorded on-chain at each step of the supply chain	(Sawtooth Lake, 2017)
Regen Network	Ecological regeneration goal achievement rewarding through fund distribution based on proof of positive land change	(Booman et al., 2018)
Traseable,	In partnership with WWF, ConsenSys, and Sea Quest Fiji Ltd to ensure tuna are collected legally and sustainably by tracking tagged tuna through supply chain	(Warburton, 2018)
Veridium	VERDE tokens are backed by carbon and other environmental credits to be used in carbon offsetting	(Verde, 2018)

4.4 Potential Conservation Uses

The conservation-specific smart contract applications identified in the previous section provided evidence of smart contract adaptability for conservation. Smart contract developer interview insights also contributed to understanding the potential uses for conservation. The technology detailed in the white papers consulted provided greater insights into smart contract technical possibilities and how this might be incorporated into conservation-specific smart contracts.

Of the 112 white papers consulted, 93 described technology applicable to this research. These papers were grouped into 6 categories (Table 4.4). Decentralised Applications (DApps) are applications which often have interfaces to aid user experience and, in this dissertation, are considered to be those that also utilise smart contracts. After analysis, 5 papers were identified to be conservation-specific (included in the previous section) and 5 mentioned use with supply chain management (however, these were not focused on sustainability). Many white papers (78) described technology that could be adapted for conservation purposes. This information, paired with data gathered from academic papers, interview insights and the current conservation uses lead to the generation of the overall potential conservation-specific smart contract applications. These have been separated into non-financial and financial applications and are summaries in Tables 4.5 and 4.6.

Table 4.4: White Paper Breakdown. A full list of papers can be found in Appendix 4.

White Paper Category	Total	Directly Conservation Related	Supply Chain Related	Possible Conservation Adaptability
Blockchain Network	31	0	1	28
Blockchain and Smart Contract Technology Contribution	2	0	0	2
Cryptocurrency or Token	5	2	0	5
Decentralised Application	49	3	4	39
Oracle Service	5	0	0	3
Token Exchange Platform	1	0	0	1

Non-financial use cases are less commonly mentioned in the academic smart contract literature, but technological abilities detailed previously in this dissertation can be used to extrapolate potential conservation implementation (Table 4.5). These applications focus primarily on automating information sharing as proof-of-goal-achievement. Examples of this include: monitoring indicators associated with the SDGs, publishing a dataset on an open-source platform, publishing an academic paper and offsetting emissions by contributing to a reforestation project. Smart contracts can further be used to distribute encrypted file access to specific individuals to maintain document privacy. They can facilitate the transfer of conservation-related objects, such as when loaning tools, museum specimens, and zoo animals to institutions, to track ownership change. Smart contracts could also be used in workflow management. This could involve the automation of information sharing once steps in a project have been completed and to identify areas within a project that restrict momentum. Smart contracts can also be used to distribute computing power, such as in artificial intelligence training and big data analytics. Although technically possible, these potential applications may not improve conservation project operations to a significant degree. This aspect is discussed in section 6.1.

Table 4.5: Potential conservation-specific smart contract non-financial applications

Area of Use	Example	Sources
Proof of Goal Achievement	<ul style="list-style-type: none"> • Sustainable Development Goals contribution • Offsetting • Publication • Data sharing • Notification of predetermined goal completion or progress • Indicator monitoring • Verification through data connection 	(Booman <i>et al.</i> , 2018; Gainforest.org, 2018; Poseidon, 2018; Verde, 2018)
Data and Document Sharing	<ul style="list-style-type: none"> • Taxonomic consistency • Peer review science • Proof of land ownership, grazing rights, etc • Record keeping • Conservation project reviews 	(Extance, 2017; Switch, 2017; Booman <i>et al.</i> , 2018; Eyholzer <i>et al.</i> , n.d.; H.C. Carvalho, Personal comm., 2018)
Distribute computational power	<ul style="list-style-type: none"> • Artificial Intelligence • Document storage 	(Wilkinson <i>et al.</i> , 2014; IExec, 2017; Booman <i>et al.</i> , 2018; DeepBrain Chain, 2018; Faceter, 2018)
Non-monetary Loan Tracking	<ul style="list-style-type: none"> • Tool loans • Specimen loans • Zoo animal loans 	(Bogner, Chanson and Meeuw, 2016; PO8, 2018)
Incentives	<ul style="list-style-type: none"> • Gamifying • Citizen Science • Rewards upon proof of goal achievement • Volunteer work • Reward sustainable actions 	(Eyholzer <i>et al.</i> , n.d.; Hilsberg <i>et al.</i> , 2016; CryptoKitties Team, 2017; Booman <i>et al.</i> , 2018; DOVU, 2018; Gainforest.org, 2018; Plastic Bank, 2018; Baynham-Herd, Personal comm., 2018; Jepson, Personal comm., 2018)
Location Monitoring	<ul style="list-style-type: none"> • Continuously track movement • Supply chain management <ul style="list-style-type: none"> • Proof of origin • Location and ownership change 	(BureauVeritasGroup, 2016; Modum.io AG, 2016; Sawtooth Lake, 2017; Trouw, Levin and Scheper, 2018; Wolberger, Lionel; Mason, Allon; Capkun, 2018; Plastic Bank, 2018)
Workflow Management	<ul style="list-style-type: none"> • Trigger next steps of project • Trigger information sharing • Identify project flow restrictions • Monitor progress towards goal achievement 	(Hilsberg, T; Robinson, A; Robinson, M; Haynes, 2016; Eyholzer <i>et al.</i> , n.d.; Conservation Investment Consultant, Interview, 2018)

Financial use cases were more frequently mentioned in white and academic papers, enabling a more confident analysis of potential conservation related financial use cases (Table 4.6). These include applying smart contracts to raise funds, trace funding flow within an organisation, control the release of funds based on proof-of-goal-achievement, and automate “feel good stories” for investors. A “feel good story” is a non-financial ROI told through the use of images, videos, and simple data that prove a positive impact has occurred (Jepson, personal comm., 2018). Pay for performance schemes were identified as a potential area of use (Conservation Investment Consultant, Interview, 2018) as well as for payments for ecosystem services (Chapron, 2017; Oberhauser, personal comm., 2018). Tokenisation to enable tradeable investments was inspired by CryptoKitties and other DApps. These financial applications have potential to become the primary use for conservation, but could be incorporated with some non-financial uses to attract investment.

Table 4.6: Potential conservation-specific smart contract financial applications

Use	Description	Source
Fund raising	<ul style="list-style-type: none"> • Direct, peer-to-peer fundraising • Crowdfunding and investment distribution where funds can be raised by multiple people and only distributed once goal has been met, otherwise funders are refunded • Create marketplace to connect investors to projects 	(Iot <i>et al.</i> , n.d.; Popov <i>et al.</i> , 2016; FriendFingers, n.d., Baynham-Herd, 2017; Booman <i>et al.</i> , 2018; gainforest.org, 2018)
Tracing funding flow	<ul style="list-style-type: none"> • Track impact • Enable token purchase and distribution as reward and use for purchase of services • Tokenise object or product to create digital representation to track income • Monetary repayment of loans • Trace what funds are spent on within a project 	(Nexo, n.d.; Farm Coin, n.d.; Eyholzer <i>et al.</i> , n.d.; Virtua, Change and Entertainment, n.d.; Modum.io AG, 2016; Baynham-Herd, 2017; Williams, 2017; Booman <i>et al.</i> , 2018; Conservation Investment Consultant, Interview, 2018)
Pay for performance schemes	<ul style="list-style-type: none"> • Automate penalties upon failure of goal achievement or missed deadlines • Distribute additional funds on goal achievement • Decrease loan interest rate on goal achievement 	(Conservation Investment Consultant, Interview, 2018)
Tradeable investments	<ul style="list-style-type: none"> • Enable investors to sell investments • Non-fungible tokens enable a digital representation of a specific investment which can be traded or sold • Potential to enable information to be shared only with those who own a specific token or a non-fungible token 	(ArkadiaLending, n.d.; CryptoKitties Team, 2017; Hertzog, Benartzi and Benartzi, 2017)
Controlled release of funds	<ul style="list-style-type: none"> • Release funds upon proof of step completion within a project 	(Conservation Investment Consultant, Interview, 2018)
Payment for ecosystem services	<ul style="list-style-type: none"> • Communities receive direct payments for restoring and maintaining ecosystem services • Esp. useful for those without access to traditional banks 	(Chapron, 2017; Oberhauser, personal comm., 2018)
Investor “feel good stories”	<ul style="list-style-type: none"> • Automatically share information of goal achievement and project updates with investors such as images, videos, publications, and data 	(Jepson, personal comm., 2018)

5. Using Smart Contracts to Attract Conservation Investment

The previous section outlined several potential financial uses that could be adopted to attract conservation investment. The primary applications identified in this study focus on the use of tokenisation for tradeable investments and investor “feel good stories” as proof-of-goal-achievement to prove non-financial ROI. EWB was used as a case study to build a smart contract model based on both of these applications.

5.1 Tokenisation

Recall from section 4.1 that non-fungible tokens are digital representations of unique objects. They are pieces of code stored on a blockchain. Unlike fungible tokens, non-fungible tokens may have different financial values from one another and cannot be divided into smaller parts (i.e. half a non-fungible token cannot be traded) (CryptoKitties Team, 2017). Each token can contain information that identifies the object and can have an image to represent the token, like CryptoKitties’ tradeable, digital cats (CryptoKitties Team, 2017). Often compared to baseball cards, non-fungible tokens create a digital collector’s item (PO8, 2018). Tokens are stored in online, digital wallets that have a unique address that smart contracts can automatically send tokens to. Because all transactions are stored on a blockchain, a smart contract can query the blockchain for the history of token sales to find the current token owner’s wallet address. This enables the transfer of keys to access encrypted files, allowing for information to be shared directly with the owners of specific tokens. Smart contracts are used to create, buy, sell and trade non-fungible tokens (CryptoKitties Team, 2017; PO8, 2018).

An EWB-specific non-fungible token, referred to in this dissertation as Herd Tokens, could be used to attract investment and distribute herd-specific non-financial ROI in the form of “feel good stories” only to those who have invested in EWB. Herd Tokens enable investors to receive unique information and because these “feel good stories” are tied to the token, investors can sell, gift or trade this non-financial ROI. Herd Tokens can be sold to receive a financial ROI.

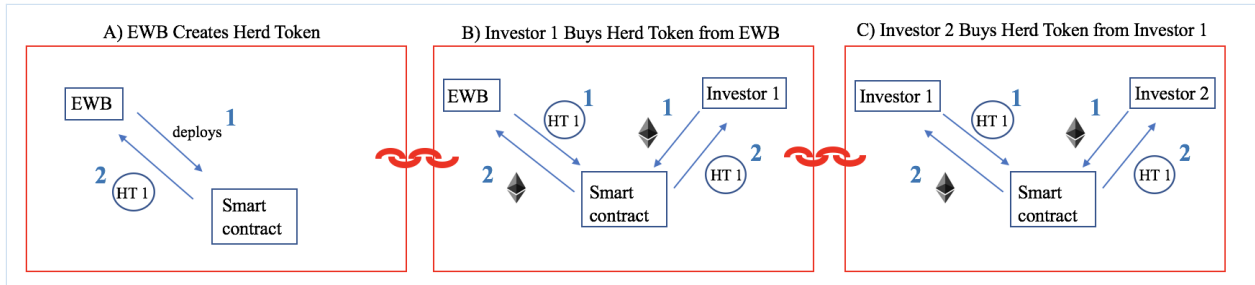


Figure 5.1: Herd Tokenisation processes using smart contracts: A) shows how EWB can create a new Herd Token; B) shows how an investor can purchase a Herd Token from EWB; C) shows how an investor can purchase a Herd Token from another investor. Transfer of funds is represented in ether, the Ethereum cryptocurrency, \blacklozenge . HT 1 represents a unique Herd Token. 1 represent which items will be transferred by whom and the 2 represents what each smart contract distributes once conditions have been met. Each transaction is stored on the blockchain in chronological order.

Figure 5.1 depicts the herd tokenisation process. Each transaction is recorded on the blockchain, ensuring Herd Token traceability. A smart contract must be used to create and distribute a Herd Token. Conditions can be included in the smart contract to ensure that only EWB can generate a Herd Token. Figure 5.2 depicts an example smart contract, showing that only EWB can generate a Herd Token. Information such as the herd's ID can be included. It is also possible to include information such as the original herd that the new herd was split from at the end of a loan period to enable herd lineage traceability. An image representing the herd can also be included with the Herd Token code for use on a user-friendly interface token information and trading platform. The smart contract also directs the Herd Token to the EWB digital wallet for storage until an investor purchases the Herd Token.

```

Adico(
  A("EWB"),
  D(may),
  I("generate", object("herd token",
    description(herd ID("Herd1"),
    origin herd ID ("Herd0")),
    target("EWB", "wallet address"))).

```

Figure 5.2: Example smart contract for herd token creation written in ADICO format

EWB can sell Herd Tokens to investors using smart contracts (Figure 5.3). In this process, an investor will send the amount of money that EWB specifies the Herd Token to be worth to the smart contract. If the investor's digital wallet contains equal to or more than the specified price, the smart contract will automatically transfer the investor's funds to EWB's digital wallet and transfer the Herd Token from EWB's digital wallet to the investor's digital wallet. The same process can be followed when an investor sells a Herd Token to another investor or when two investors trade Herd Tokens. An additional step of ensuring the investor selling the Herd Token owns the specific token will be included in the smart contract by the same process of ensuring that a token purchaser has the available funds in their wallet prior to token transfer.

```

Adico(
  A("investor 1"),
  D(may),
  I("send", object("herd token price",
    target("EWB", "wallet address"),
  C("IF", "investor", "wallet address", "holds", ">=price"),
  AND
    A("EWB"),
    D(must),
    I("send", object("herd token",
      target("investor", "wallet address"))).

```

Figure 5.3: Example smart contract for investor purchase of a herd token written in ADICO format

5.2 Proof-of-Goal-Achievement

Smart contracts can also be used to provide proof of goal achievement or “feel good stories” as a non-financial ROI. Connection to an oracle service is necessary for adoption of smart contracts for this purpose to access data not on a blockchain. This requires data to be accessed remotely, whether it be from online databases, online data platforms or IoT-enabled devices. Indicators taken from RE’s impact indicators (van de Vlasakker, 2014) were used to provide 2 examples of EWB-specific proof-of-goal-achievement.

The first example focuses on the EWB goal of carbon sequestration and land change based on the EWB indicator: *extension of the area with spontaneous native forests and natural tree regeneration*. It depicts the use of GEE to return both forest growth information and a visual in the form of a time series video that GEE can generate to provide a “feel good story” to investors. Figure 5.4 demonstrates the steps taken using smart contracts to provide this information.

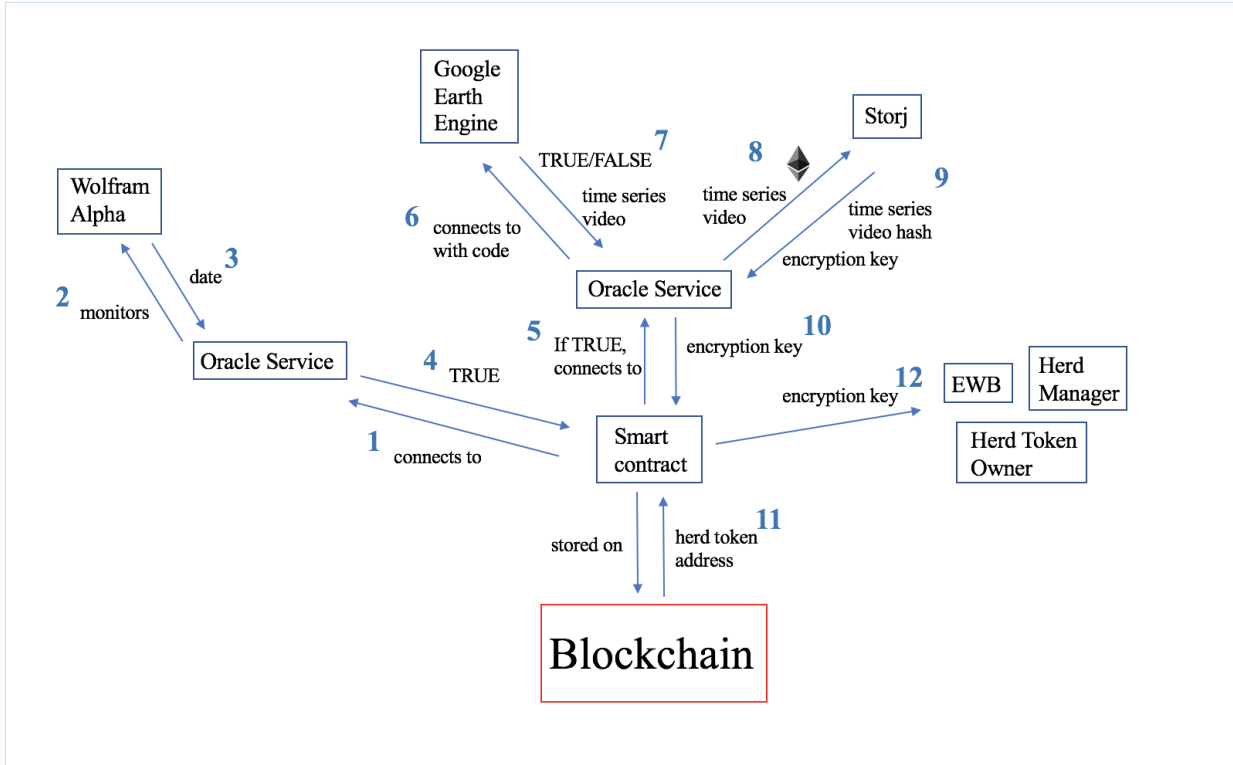



Figure 5.4: A depiction of steps taken to achieve proof of goal achievement: numbers indicate order of steps taken and arrows indicate directional flow of information or funds. Ether, , is used to depict payment to use Storj. The smart contract code is stored and executed on the blockchain. The outcomes of the smart contract are also stored on the blockchain.

In this example, an oracle service is used to monitor a predetermined date in which the analysis is due to take place. This is required to ensure the smart contract is executed on the intended date, avoiding errors caused by differing block timestamps in differing time zones (Alharby and Van Moorsel, 2017). A common date information source used by smart contracts is Wolfram Alpha (Smart Contract Developer, Interview, 2018). An oracle service would monitor Wolfram Alpha until the intended date is reached. At this point, the oracle service would return “TRUE” to the smart contract, triggering the next step. This would cause the smart contract to connect to an oracle service to carry out simple analysis using GEE. A smart contract can store GEE code written prior to smart contract deployment. The GEE code could specify the analysis that needs to take place, i.e. analysing the percent forest growth between specified dates using GEE satellite images of the specified area. The oracle service can then return either the exact percentage or “TRUE/FALSE”

if EWB is focused on meeting a specific growth percentage goal. Additionally, GEE enables the creation of time-lapse videos that show the change in satellite images over time. An oracle service can take this video and upload it to an encrypted file storage site, such as Storj (Wilkinson *et al.*, 2014). This may require a cryptocurrency payment, which a smart contract can automatically distribute from the EWB digital wallet. Alternatively, the oracle service can encrypt the file and upload it to an EWB platform. The oracle service will then return the encryption keys to the smart contract which will enable only those in possession of the keys to view the encrypted file. The smart contract will then distribute the keys to specified individuals, such as EWB and herd managers. EWB can also specify in the smart contract the specific Herd Token that corresponds to the herd responsible for the potential forest growth. The smart contract can query the blockchain to determine the current owner of the Herd Token and send an encryption key to a specific investor. The time-lapse video would serve as proof-of-goal-achievement, a “feel good story” and prove non-financial ROI. More details of this smart contract example of depicted in ADICO format in Figure 5.5.

```

Adico((
  A("oracle service"),
  D(must),
  I("connect", object("WolframAlpha"),
  AND
    I("return", object("TRUE"),
      target("smart contract hash"),
    C("IF", "date", "=03/09/18"),
    O(Adico(
      A("oracle service"),
      D(must),
      I("monitor", object("WolframAlpha"))),
    AND
      C("IF", object("TRUE"),
      A("oracle service"),
      D(must)
      I("connect", object("GEE"),
      AND
        A("oracle service"),
        D(must),
        I("deploy", object("GEE code"),
      AND
        I("return", object("TRUE"),
        C("IF", "% forest increase", ">=5"),
        O("return", object("FALSE"),
      AND
        C("IF", object("TRUE"),
        I("return", object("time series video"),
          target("storj"),
      AND
        I("return", object("video hash"),
          target("smart contract hash"),
      AND
        I("return", object("encryption key"),
          target("smart contract hash")),
      A ("smart contract hash"),
      D (must),
      I ("query", object("blockchain"),
      AND
        I("return", object("current herd token 1 owner wallet
address"),
          target("smart contract hash"),
      AND
        I("send", object("encryption key"),
          target("EWB", "wallet address", "herd manager",
"wallet address", "herd token 1 owner", "wallet
address"))).

```

Figure 5.5: Example of smart contract using connecting to Google Earth Engine (GEE) to provide evidence of forest growth: An oracle service is contacted and told to connect to Wolfram Alpha and return "TRUE" to the smart contract if the date is 3 September 2018. If the date is not 3 September 2018, the oracle service must continue to monitor Wolfram Alpha. If "TRUE" is returned, an oracle service must connect to GEE, deploy GEE code, return "TRUE" if percent change is greater than or equal to 5 percent or return "FALSE" if less than 5 percent. If "TRUE", the oracle service must return the time series video to Storj and return the file hash, or identification number, and the encryption key to the smart contract by searching the blockchain for the smart contract hash. The smart contract would automatically distribute payment from the EWB digital wallet to Storj to pay for the service (not shown in figure). The smart contract will then query the blockchain to determine the current Herd Token owner's digital wallet address. It will then distribute the encryption keys to the EWB, herd manager, and current Herd Token owner digital wallets.

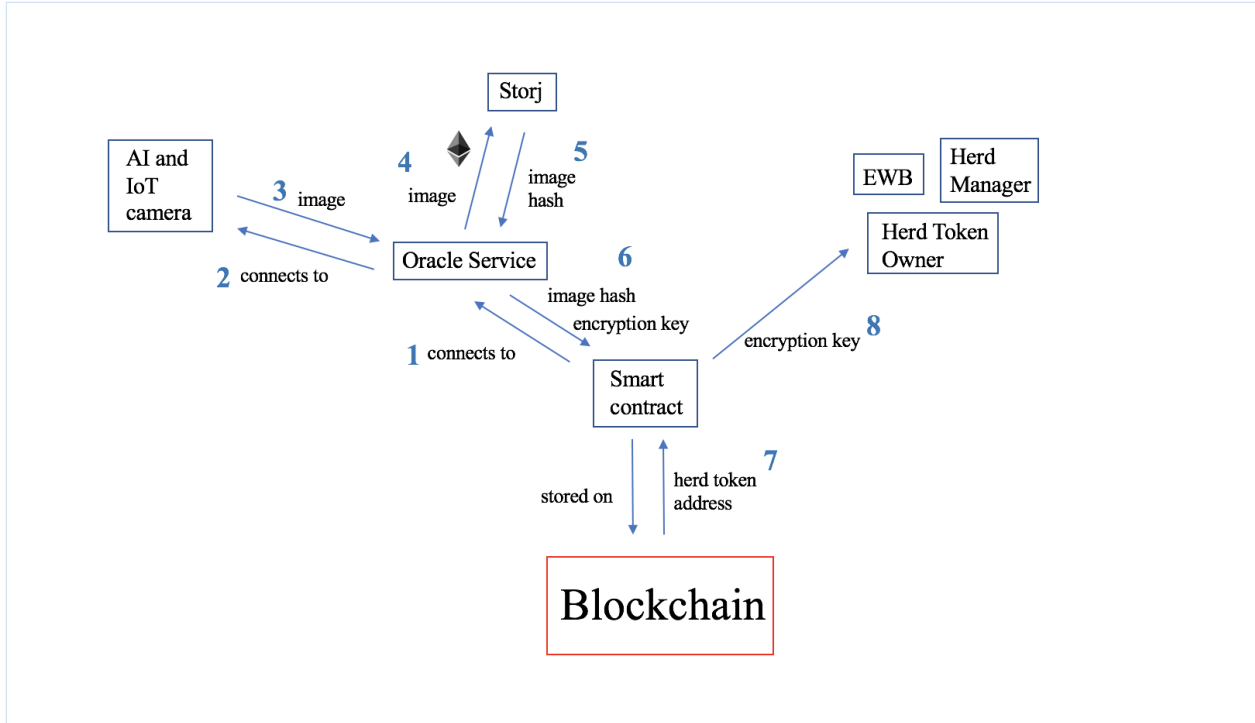


Figure 5.6: Depiction of steps taken for smart contract to return specific images to EWB, a herd manager and a specific Herd Token owner: Numbers indicate order of steps taken and arrows indicate directional flow of information or funds. Ether, \blacklozenge , is used to depict payment to use Storj. The smart contract code is stored and executed on the blockchain. The outcomes of the smart contract are also stored on the blockchain.

The second example focuses on the goal of increasing biodiversity using the EWB indicator: *variety of key large herbivores, carnivores and scavengers present in natural densities*. This example utilizes an IoT-enabled trail camera that has artificial intelligence capabilities to automatically identify species captured in images (Elias *et al.*, 2017). Although no EWB herd manager is currently in possession of this technology, the example is used to illustrate how this technology could automate image analysis and sharing to decrease human involvement and increase cost-effectiveness as an additional attraction for investors. Figure 5.6 shows the steps taken in this example. A smart contract would connect to an oracle service to collect relevant images from an AI and IoT-enabled field camera. The oracle service would upload these images to an encrypted file storage platform, either Storj or an EWB platform. The oracle service would return the image hash and encryption key to the smart contract which would return the key to specified individuals, such as EWB, a herd manager and the current Herd Token owner

corresponding to the site where the field camera is located. This process is similar to the previous example. Figure 5.7 outlines this example in ADICO format.

```
Adico(  
  A("oracle service"),  
  D(must),  
  I("connect", object("camera")  
  AND  
    I("return", object("wolf image"),  
      target("storj"),  
    AND  
      I("return", object("image hash"),  
        target("smart contract hash"),  
    AND  
      I("return", object("encryption key"),  
        target ("smart contract hash"),  
  A ("smart contract hash"),  
  D (must),  
  I ("query", object("blockchain"),  
  AND  
    I("return", object("current herd token 1 owner  wallet  
address"),  
      target("smart contract hash"),  
  AND  
    I("send", object("encryption key"),  
      target("EWB", "wallet address", "herd manager",  
"wallet address", "herd token 1 owner", "wallet  
address"))).
```

Figure 5.7: Example of smart contract using connecting to AI IoT-enabled camera to provide evidence of wolf presence: A smart contract would connect to an oracle service which would then connect to an IoT-enabled field camera. If available, the oracle service would extract relevant images, in this example an image identified to contain a wolf. This image would be uploaded to Storj and the image hash and encryption key returned to the smart contract. The smart contract would distribute payment from the EWB digital wallet to Storj (not shown in figure). The smart contract would then query the blockchain to identify the specific Herd Token's current owner's wallet address. The smart contract would then distribute the encryption key to the EWB, herd manager, and current Herd Token owner's digital wallet addresses.

For both examples, smart contracts can also be used to notify individuals when an object (cryptocurrency payment, a Herd Token, or encryption key) is transferred to their digital wallet, such as seen in Coinbase. These notifications can be email- or SMS-based when contact details

are linked to a user’s digital wallet. These notifications may prompt a user to check the information transferred through the use of a user-friendly interface platform or DApp. It is also possible to use a smart contract to prompt an artificial intelligence algorithm to generate a natural language report of smart contract outputs to ease in user understanding of outcomes (Nugent, Upton and Cimpoesu, 2016).

Figure 5.8 depicts the potential information that could be stored on an EWB blockchain. This includes records of herd token creation and sales, land change data and image and video hashes. Figure 5.9 provides an example of what an EWB blockchain could look like given the sequential recording of these model smart contract transactions. The EWB model’s ability to attract investors will be discussed in the following section.

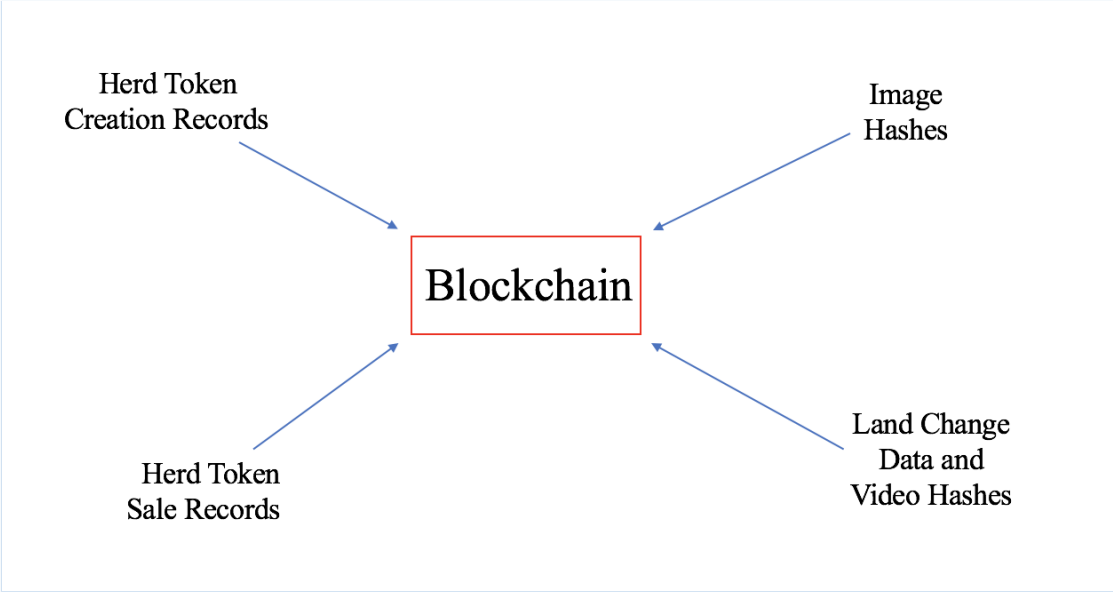


Figure 5.8: Information shared and stored on an EWB blockchain

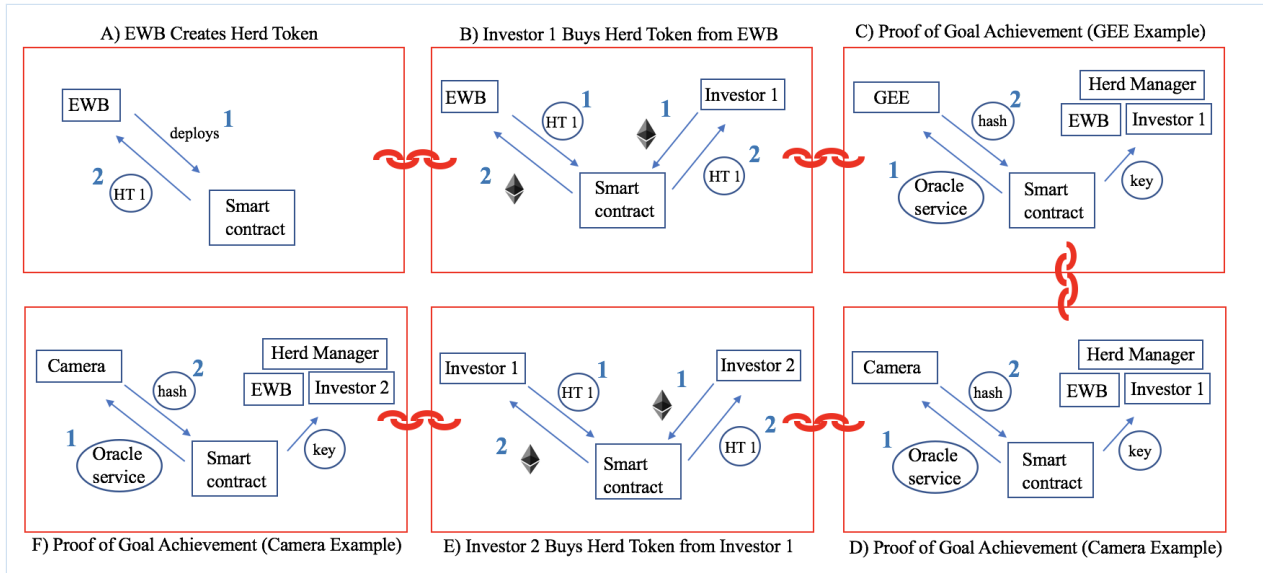


Figure 5.9: Example of a sequential smart contract transaction: The creation (A) and sale (B; E) of a Herd Token are shown; the proof-of-goal-achievement examples directed at an initial investor (C; D) and directed at a second investor (F) after the initial investor sells the Herd Token to a second investor are also visualised.

6. Discussion

6.1 Smart Contracts Affordance to Conservation

This dissertation has focused on the possibility of utilising smart contracts to attract conservation investment. To do this, the possibilities and limitations of this technology were first explored, along with the conservation tools that can be integrated. Current and potential uses were outlined, leading to the presentation of a model smart contract specifically designed to attract conservation investment. While this last aspect was a major focus of this dissertation, the research has revealed insights into the broader affordance of smart contracts for conservation.

Recall that smart contracts are essentially automated computer programmes. These programmes facilitate the secure transfer of information or digital assets (i.e., cryptocurrencies and digital representations of real world objects) in a decentralised way. Additionally, they enforce agreements and can trigger transactions to occur only when a condition is met. Due to their connection with blockchain and the high level of transparency that blockchains afford, smart contracts eliminate the need for trust between peers. For conservation, smart contracts ultimately increase efficiency by decreasing the need for human involvement, whether it be for fund transfer or data sharing. Different types of blockchains can enable information to be private and shared with only those with permissioned access or fully transparent and available for all to see. Although this possibility for conservation has sparked discussion over potential implementation (Baynham-Herd, 2017; Chapron, 2017), their actual affordance to conservation is restricted by several technical limitations.

The most considerable limitation of smart contracts is their inability to connect to outside world data. Although oracle services solve this problem, understanding oracle technology reveals significant limitations to conservation implementation. Because oracle services enable remote connection to data providers, the data that can be used to trigger a smart contract or be shared with individuals is highly limited. Data must therefore be shared in an online database or enable direct remote access, such as with an IoT-enabled device. To get around this problem, conservation projects could upload field data to an online database, such as GBIF, and use an oracle service to connect to GBIF to confirm the dataset's existence. The same logic can be applied to online

journals for proof of publication: upon proof that a research paper has been published, the next round of funding could be automatically released, for example. Oracle services can also be used to automate simple data analysis, such as by connecting online-accessible data to GEE to measure percent land change between pre-specified dates. These applications can return percentages or TRUE/FALSE values to a smart contract, enabling nodes in a network to easily determine things such as whether a goal has been achieved. Smart contracts can therefore simplify conservation reporting while decreasing human involvement. Using oracle services with IoT-enabled devices enable more applications that decrease human involvement, such as triggering a field camera to turn on when a tracked animal comes within range. Oracle services are key to most conservation smart contract applications. However, a cost analysis may reveal that implementation of this technology may be higher than the usefulness they afford. In addition, the current limitations of oracle services with regard to file sharing further limits conservation implementation.

Although technically possible, the computational cost associated with file transfer and storage makes using smart contracts for this purpose impractical. Several companies, such as Storj, present solutions to this problem. Oracle services can automate the distribution of files to such companies. These services are required for any smart contract application that involves providing proof of documentation (i.e., land rights, project reports) or sharing files (i.e., images, videos) with pre-specified individuals. Smart contracts can automate aspects of file sharing while solving issues of trust in corrupt systems. However, it is questionable if this is necessary for conservation. Although corruption might be prevalent in some conservation projects located in developing areas (Frewer, 2013), further research should be conducted to determine if a decentralised file sharing system is fit for purpose for tackling this issue. In all other cases, existing software that does not require the use of smart contracts to store and share files may be a better fit for efficient document sharing. Google Drive is one such example. Although automating file transfers to specific individuals may increase efficiency by decreasing human involvement, the requirements associated with using smart contracts for this purpose seem unrealistic for conservation. Although both oracle services and distributed file sharing systems can be useful for some conservation applications, an additional limitation must be considered prior to adoption.

For both oracle services and blockchain-based distributed file companies, cryptocurrencies are required for service payment. This significantly constrains the implementation of smart contracts

in most conservation cases, requiring conservation projects to purchase a cryptocurrency. Cryptocurrencies present two problems for conservation: they are not widely accepted and are highly volatile. Most cryptocurrency transactions occur in Europe and the United States, indicating greater use of this cryptocurrency in highly developed regions, an expected result due to internet connectivity requirement for use (Lischke and Fabian, 2016). This therefore excludes highly remote or underdeveloped conservation project regions from engaging with cryptocurrencies, and smart contracts in general. It also indicates a limited number of individuals that accept a cryptocurrency over fiat for payment for products and services. Additional research is required to estimate the acceptance of cryptocurrencies within the conservation sector. Additionally, cryptocurrencies are highly volatile (Lee, Guo and Wang, 2018). The price of Bitcoin dropped from US\$20,000 in December 2017 to US\$6,000 in February 2018 (Kreuser and Sornetter, 2018). The potential for future price drops can discourage donors and put conservation project funds at risk. In a sector plagued by financial insecurity, engaging with cryptocurrencies can be seen as irresponsible (Conservation Investment Consultant, Interview, 2018). Although there are solutions to this problem (i.e., using a fiat-backed cryptocurrency or enabling the direct exchange of fiat on a smart contract platform), most applications will require conservation projects to hold a cryptocurrency, severely limiting potential uses for those who wish to avoid adopting a cryptocurrency.

Although it is possible to implement both a conservation-specific oracle service and blockchain-based file sharing system which would not require a cryptocurrency payment, it then begs the question if this technology is even necessary for conservation. Oracle services enable more smart contract applications that decrease human involvement. The purpose of a blockchain-based file sharing system is to: ensure that documents are shared, enable only specific individuals to view documents and ensure permanent document existence (Wilkinson *et al.*, 2014). Both of these applications' primary use is to enforce an agreement, such as data and document sharing, or that an action is carried out when a condition is met. This therefore eliminates the need for trust, which can be beneficial in corrupt and low-trust networks. But is this really a problem in conservation? If smart contracts afford most to automated transactions to increase efficiency for conservation, then a cost analysis must be conducted to further determine if this technology is fit for this purpose. Another limitation of smart contracts is the complexity of language, which can lead to significant errors. This then requires either conservationists to learn smart contract coding skills or partner

with smart contract developers. Both options add to implementation cost. Further, the restrictions of what tools and technologies can be integrated with smart contracts poses additional costs associated with smart contract adoption, limiting the usefulness of this technology.

Analysis of the 126 conservation tools identified in this dissertation to understand possible integration with smart contracts reveals the degree of affordance smart contracts offer to conservation. It became clear in each of the 8 tool categories that only those tools that enable remote access to data captured and collected can be integrated with smart contracts by using an oracle service. This includes field cameras, audio recording devices and tracking devices that automatically send their data to a cloud through Short Message Service (SMS), Bluetooth and other IoT technology. Additionally, field data collected using applications which automatically share data with a cloud-based database could be used in connection with smart contracts. Online data analysis tools, such as GEE and Zooniverse, could be used in connection with smart contracts to perform analysis or monitor progress towards goal achievement. Connecting to online information platforms and open databases, including open natural history databases, online maps, and accessible satellite imagery, offers the most connectivity to smart contracts. Other tools, such as those used to raise funds (i.e., Kickstarter) and report generation tools, can instead use smart contracts for these purposes directly. Overall, most conservation smart contract applications will require projects to either utilise remote-accessible equipment or rely on online databases. This conclusion may limit the usefulness of smart contracts to specific conservation applications.

As previously outlined, smart contract adoption is restricted by multiple technological limitations. This may explain the limited number of current conservation uses. Exploratory research revealed only 11 applications specifically related to conservation. Five concern proof-of-goal-achievement, 3 focus on supply chain management to prove legal provenance of animal and plant products, 2 involve offsetting and 1 was a single case of selling a non-fungible token to raise funds for conservation. The proof-of-goal-achievement and offsetting cases utilise digital tokens or cryptocurrencies to incentive positive conservation impact behaviour. These range from species identification (bioBIT Network), to plastic recycling (Plastic Bank), to protecting forests (GainForest) and habitat restoration (Regen Network). Each case relies on data connectivity, whether it be for using satellite images (GainForest) or monitoring an online database such as iNaturalist (bioBIT Network). Digital rewards are then used for such things as conservation service

payment (Porini Foundation). Although not explicitly mentioned, the reliance on oracle services and cryptocurrencies will limit the scalability of each project to those in highly connected areas and those that can manage the volatility and limited acceptance of cryptocurrencies. Issues with scalability surfaced with supply chain management smart contracts (Bureau Veritas Groups, Provenance and Traseable). Although proving legal origin of products will increase consumer knowledge of sustainability, therefore positively effecting the conservation of threatened and endangered species, scalability relies on both ensuring the extraction location data to be truthful and the purchase of many tracking devices. While the first may involve partnership with a trusted NGO or certification system (Traseable's partnership with WWF), the second will require either the purchase of hardware or the use of such things as QR codes. The latter is more cost efficient, but will require each product to be scanned at every step of the supply chain. Both offsetting uses and the sale of CryptoKitties' Honu require the transfer of cryptocurrency. Both introduce the necessity of conservation projects to hold this volatile currency and either transfer to fiat or find another conservation project to accept the cryptocurrency for payment. While the first option is more likely due to cryptocurrencies not yet being widely accepted (Smart Contract Developer, Interview, 2018), both options introduce an unnecessary complication and again beg the question, are smart contracts fit for these purposes? Although each current use presents a technologically feasible smart contract application, the limitations of scalability bring into question whether the cost of implementation for limited use is worthwhile. With these current uses and the technical possibilities of smart contracts in mind, potential future conservation implementation was explored.

Overall, potential uses fell into two categories: financial and non-financial. Although technically possible, each potential use identified may not be practical for conservation implementation. For reasons mentioned above, proof-of-goal achievement and information sharing is restricted to specific tools and may require conservation projects to adopt cryptocurrencies to pay for oracle and file storage services. Although using smart contracts to monitor locations of tools, specimens, individual animals and products may be technically feasible, implementation will require adopting tracking technology and may contribute no additional benefit to current tracking systems in place. Incentivising with digital tokens or cryptocurrencies, along with all potential financial uses identified, comes with the issues associated with cryptocurrencies discussed above. Internal use in workflow and financial management may be the most useful possibility identified due to the

potential to increase efficiency by decreasing human involvement. This case also has potential to be used to attract investment based on the increased transparency it affords. However, this use is also subject to the limitations associated with data and file connectivity. Although some potential uses may provide more benefits than others, each use explored is limited by the technical affordance of smart contracts.

This exploratory research has predominantly revealed that although there are a number of potential uses for smart contracts within conservation, limitations involving scalability, the financial cost of implementation and the implications of holding a cryptocurrency may limit what smart contracts can currently afford to conservation. More research is needed to determine which of the potential uses, if any, contribute significantly to increasing conservation efficiency through decreased human involvement and whether smart contracts are best fit for purpose for these tasks through cost-benefit analyses. The second phase of this research explored the specific application of using smart contracts to attract conservation investment and will be discussed below.

6.2 Smart Contract Use to Attract Conservation Investment

The affordance of smart contract for conservation, specifically the potential uses identified in the exploratory research, revealed several applications that could be used to attract conservation investment. Peer-to-peer fund distribution, controlled fund release based on goal achievement and funding flow traceability may attract investment because of the decreased transaction cost and increased financial transparency that smart contracts afford. They also decrease investment risk as smart contracts can automate fund release based on conditions, such as proof-of-goal-achievement. Proof-of-goal-achievement, increased connectivity of data and files and the automated sharing of “feel good stories” can act as a nonfinancial ROI. Tokenisation creates a digital asset that can be traded and invested in (as demonstrated by CryptoKitties’ Honu). It also enables nonfinancial ROI to be automatically distributed only to those who have invested in a specific conservation project and has potential for investors to receive a financial ROI through the sale of this digital asset. Based on these potential uses and aspects of EWB operations and identified areas of improvement, the specific smart contract model created focused on tokenisation and proof-of-goal-achievement through investment-specific “feel good stories”.

While the EWB model's depiction of tokenisation through the creation of Herd Tokens presents an intriguing use for conservation smart contracts, it is not without its limitations. Herd Tokens create a unique digital collectable. Because EWB could create a limited number of Herd Tokens, smart contracts could then be used to create digital scarcity, potentially leading to appreciation, as shown with the rising price of CryptoKitties (Vox, 2018). Although Herd Tokens would only provide EWB with a financial impact at the time of sale, this potential appreciation would enable investors to gain a financial ROI through selling the token to another individual. This would eliminate the need for EWB to provide a financial return to investors. This, however, relies on there being a market for Herd Tokens. Although the sale of CryptoKitties' Honu indicates a current interest in conservation-related non-fungible tokens, additional research is required to discover the extent to which this is true. Further, interest in CryptoKitties may stem from the appealing images attached to each token, the user-friendly interface developed and the ability to breed these digital kitties. More research is needed to determine if gamification is the primary attraction to CryptoKitties, at which point more research will be needed to determine how Herd Tokens could adopt a gamification aspect. Although tokenisation could appeal to investors, this use does not escape the limitations associated with cryptocurrencies. The adoption of Herd Tokens would require EWB to engage with cryptocurrencies, forcing them to adopt volatility risks. This factor would also limit potential investors to those who engage with cryptocurrencies. For example, some largescale investors, such as pension funds, may be unwilling to risk cryptocurrency volatility. Additional research into cryptocurrency-based investment is needed to further reveal a potential market for Herd Tokens. Currently, scalability is limited and the sale of Herd Tokens may not dramatically impact EWB operational costs.

Despite these limitations, implementation of Herd Tokens is low cost as it does not require the use of oracle or distributed file services and can use existing non-fungible token creation platforms, such as Ethereum. However, attaching "feel good stories" through proof-of-goal-achievement as a non-financial ROI will require additional measures, and could increase investor interest in Herd Tokens. As the model shows, impacts and EWB goal-achievement can be herd-specific. This would enable investors to receive information directly tied to their investment. It also enables this information to only be shared with a specific Herd Token owner, which may further increase the attraction of Herd Tokens based on the incentive to gain access to private information. Because the blockchain records all transactions, a smart contract can automatically direct this information

only to the current Herd Token owner, ensuring that previous owners would not continue to receive information after sale and eliminating the need for EWB to keep track of current Herd Token owners. This would, however, require EWB to limit public reporting or only report general goal achievement in public reports. Additionally, exploring this use case made the restrictions of smart contract affordance more apparent. While sharing images and videos with specific Herd Token owners can be automated to decrease human involvement, it requires the use of a decentralised file storage system. Data connectivity requires an oracle service to utilise such things as satellite imagery for proof of landscape change and potentially requires IoT-enabled devices (i.e., field cameras and animal tracking devices) for additional data connectivity. Both of these requirements invoke an unavoidable additional implementation cost. Because of the limited data connectivity and potentially high cost of implementation, the question of whether or not smart contracts are best fit for purpose for herd-specific proof-of-goal achievement is raised. Perhaps it would be more cost effective, albeit less automated, to keep track of current Herd Token owners by querying the blockchain and manually sending herd-specific images, videos and data instead of implementing smart contracts. A cost-benefit analysis or further discussion is required to determine if the benefits of smart contracts outweigh the costs for EWB.

Based on the EWB model and the exploratory research, it is feasibly possible to use smart contracts in ways that could appeal to investors. However, this attraction may not include large scale investors and will only be attractive to investors willing to utilise cryptocurrencies. Although more research is needed to understand the overlap between conservation investment and cryptocurrency-based investment, it is unlikely that smart contracts can be used to mobilise large amounts of private capital by appealing to conservation investors. Further, it is unclear whether or not a market exists for conservation tokenisation and “feel good stories” as a nonfinancial ROI. Although the sale of CryptoKitties’ Honu indicates a willingness to purchase a tradeable digital asset for which funds are directed to a conservation initiative, this was a one-time sale with no long-term benefit for conservation. Although smart contracts are generating buzz in the financial industry, their implementation for the sake of implementation will not attract investment without a clear business model and potential return on investment (Conservation Investment Consultant, Interview, 2018). Additionally, further research should be conducted to determine whether the cost of implementation is worth the limited affordance of smart contracts for conservation.

7. Conclusion

The exploratory research and model developed revealed that smart contracts currently afford very little to conservation. Smart contracts are purely computer programmes that automate processes. They are often compared to vending machines (Szabo, 1997), meaning they automate simple transactions. Conservation, however, is not comparable to a vending machine, as it is not comprised of clear, simple transactions. The complexity of conservation therefore limits smart contract implementation only to clear-cut exchanges of funds or information. A number of uses to automate these types of transactions have been identified. However, scalability and the cost of implementation indicates that smart contracts will not be successfully implemented at scale and are only practical at the project-specific level. The necessity of remote accessible data restricts implementation to project-specific cases with financial capabilities of utilising these technologies. Without remote accessible data capture devices, uses are limited to online databases, further restricting conservation-specific smart contracts. Further, the required use of a cryptocurrency is necessary in almost all applications, introducing volatility to already limited conservation funds. Additionally, smart contracts may not be best fit for purpose for desired outcomes. For example, if more efficient data sharing is desired, other technology, such as Google Drive, is more fit for purpose than smart contracts. Although current uses have been described, widespread implementation is unlikely to occur.

This same conclusion can be applied to smart contracts in the context of conservation investment. While smart contracts are technologically capable of conservation investment applications, they are not fit for purpose to attract conservation investment on a scale that will significantly contribute to tackling the conservation financial problem. Smart contracts may attract investors who are interested in diversifying their digital asset portfolios, but these individuals only represent a small portion of investors and it is unclear how many of these investors are interested in collecting non-financial ROI in return for a significantly reduced financial ROI. Further, these individuals are unlikely to contribute significant sums to conservation. Cryptokitties' Hona sold for US\$25,000 (32auctions, 2018), indicating the sale of conservation tokens may attract conservation investment, but would not greatly impact the billions required to fully fund conservation efforts (Kaiser, 2015).

Although smart contracts have been described as a disruptive new technology (Risius and Spohrer, 2017), they are unfit for the purpose of mobilising significant private conservation capital.

This research provides further evidence of the complexity of conservation and issues of financing a sector that generates virtually no financial return. Although interest in impact investment is rising (Baumann *et al.*, 2017) and the conservation sector is beginning to incorporate more emerging technologies within conservation practice (Pimm *et al.*, 2015), smart contracts will not play an impactful role in solving the conservation financial crisis at this time. There is potential for smart contracts to become more fit for purpose with time as technology costs decrease, enabling more conservation projects to adopt emerging technologies (August *et al.*, 2015). The conservation sector should therefore continue to explore alternate funding options and the incorporation of emerging technologies to solve the conservation financial crisis.

8. Limitations

This research was limited by several factors. These things included the need to priorities which smart contract technical aspects to explain. This left such things as cryptography and block mining out of this dissertation. Further, this dissertation could have benefited from additional interviews with conservation investors and cryptocurrency investors to draw further conclusions on smart contract affordance to attracting conservation investment. A cost-analysis of smart contract EWB implementation would have furthered revealed if smart contracts were fit for purpose for EWB investment attraction. Additionally, the final smart contract model created could have benefited from consultation with smart contract developers to confirm technical aspects were sound.

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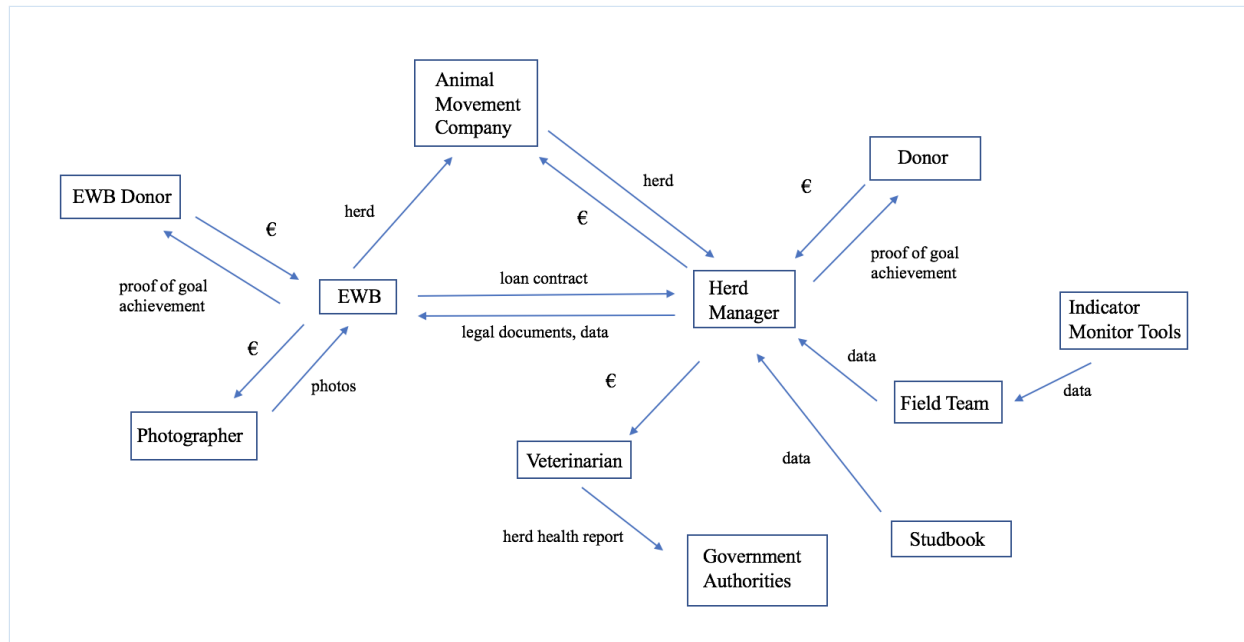
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10. Appendices

Appendix 1: Additional EWB Information

All information gathered from EWB interviews responses.



Appendix 1, Figure 1: Movement of funds (shown here as €) and information between individuals involved in EWB

Appendix 1, Table 1: EWB Goals

EWB Goals		
Increase biodiversity	Decrease wildfires	Prove mega herbivores have value
Carbon sequestration	Decrease human-wildlife conflict	Generate income through restoration
Increase natural grazing	Create wildlife currency	Incentivize land regeneration

Appendix 1, Table 2: Requirements prior to signing a loan contract and responsibilities of herd managers while in control of a herd

Required Before Signing	Responsibilities After Signing
Proof of land and grazing rights	Dispose of dead
Proof of adequate water	Maintain animal wellbeing
Proof of suitable habitat i.e. open space, forest for shelter	Enable adaptation to weather and predators
Proof of natural barriers or fencing to limit migration	Restrict unwanted crossbreeding
Proof of correct food type	Enable student researchers access to herds
Proof of adequate food quantity	Provide extra fodder and veterinary care only when lives are at risk
Proof of breeding and management skills	Pay for veterinary checks before and after herd movement
Assessed risk of human-wildlife conflict (distance from agricultural land and infrastructure, herd manager relationships)	Comply with government regulations i.e. yearly veterinary checks

Appendix 1, Table 3: Additional EWB animals and cost information

Animal Information		Cost Information	
Number of Animals	800-850	Animal Purchase cost	€500
Current Animal Species	wild horse species, cow breeds belonging to the Taurus Foundation, European bison, ibex	Animal Translocation Cost (paid by recipient)	€350 to €500 per animal
Future Animal Species	water buffalo and kulan	Administration fees	€10,000 per year per 1000 animals
Herd Size	10 to 150 animals	Additional costs	Veterinary fees pre- and post-animal movement

Appendix 1, Table 4: Examples of types of data collected by herd manager field teams

Data Collected	
<ul style="list-style-type: none"> • Number of births, deaths, total herd size • Hectares of land grazed and herd range • Genetic information where possible i.e. parent-offspring observations, copulation observations, blood tests • Herd health status 	<ul style="list-style-type: none"> • Landscape change surveys • Soil and water quality surveys • Animal image capture with trail cameras • Biodiversity surveys

Appendix 1, Table 5: Areas identified for improvement and limitations of utilising smart contracts to meet these improvements

Areas for Improvement	Limitations
<ul style="list-style-type: none"> • Ability to track herd movement i.e. to ensure grazing within legal areas and for donor updates • Automated data connectivity and sharing i.e. population growth statistics and land impact data between EWB, herd managers and donors • Trace genetic lineages of individuals • Collect better land impact data • Herd reporting accuracy • Link data with herd contracts for automated notifications and to aid loan renewal decisions • Increase emotive involvement of potential investors through image and video sharing • Trace investor funds to specific herd • Prove to investors of efficient and effective use of funds • Engage in activities that could provide a monetary return on investment i.e. beef sales, trophy hunting, ecotourism, grazing for fire protection services • Utilize technology i.e. location monitoring devices, GPS/GIS and satellite imagery for data gathering and analysis, IoT enabled train cameras 	<ul style="list-style-type: none"> • Limited access to GPS, remote sensing, data capture technology • Tracking devices on horses must be physically scanned by handlers and do not enable remote scanning • Purchase of additional or improved tracking devices requires funding • Animal location data is not openly shared • Collecting genetic information costs are high • Estimating parent-offspring relationships relies on observations, which are difficult on large sites • Government restrictions limit interference i.e. bison interactions are limited to counting • Loan renewal decisions cannot be automated

Appendix 2: Web Articles and YouTube Videos Consulted

Non-academic web articles, informal blogs, “How To” guides and YouTube videos were consulted during background research to provide a base knowledge prior to consulting academic and white papers. Searches for this material were conducted on Google and YouTube using the search strings “bitcoin”, “blockchain”, “smart contract”, and any technical terms not understood when reading whitepapers, such as “oracle” and “block mining.” The Facebook group Blockchain Enthusiasts – The New Frontier (https://www.facebook.com/groups/1652503914790213/?ref=group_browse_new) was manually scrolled through to also identify material. Articles referenced in other articles were also consulted. A total of 31 YouTube videos and 29 non-academic web articles, online magazine articles, blogs, and question forums were consulted. A list of these can be found in the table below.

Appendix 2, Table 1: Non-academic sources consulted for background research

Title	Author	Date	Type	Web Link
Why people are buying cartoon cats on the blockchain	Vox	24-May-18	YouTube Video	https://youtu.be/jGfvkjzLrNw
What is Bitcoin Mining?	BitcoinMining-Com	9-Apr-13	YouTube Video	https://youtu.be/GmOzih6I1zs
How to Read an Ethereum Blockchain Explorer Receipt	Blockchain WTF	29-Sep-17	YouTube Video	https://youtu.be/7yAxcKabNNM
MetaMask Introduction	MetaMask	14-Jul-16	YouTube Video	https://youtu.be/6Gf_kRE4MJU
Ultimate Intro to Ethereum Dapp Development [Part 12] - Oracles and Oraclize	Decypher Media	17-Nov-17	YouTube Video	https://youtu.be/04WiDy_Of2A

ChainLink (LINK) - Decentralized Oracle for Smart Contracts	Crypto Love	1-Oct-17	YouTube Video	https://youtu.be/kn0LHq0aItg
Difference between DAPPS and Smart Contracts? Programmer explains.	Ivan on Tech	9-Mar-18	YouTube Video	https://youtu.be/4rczD8xKPJc
Simple introduction to smart contracts on a blockchain	Chainthat	6-Dec-15	YouTube Video	https://youtu.be/FkeLDPZ-v8g
Meet Earth Engine	Google Earth	17-Jan-17	YouTube Video	https://youtu.be/gKGOeTFHnKY
Datawallet: Make your data work for you	Datawallet	8-Jan-18	YouTube Video	https://youtu.be/vsS_li7aArc
Introducing Datum - #TakeBackYourData	Datum	10-Sep-17	YouTube Video	https://youtu.be/NOTIH2sS1C4
Tokenizing real-time data - Streamr explained in 2 minutes	Streamr	2-Aug-17	YouTube Video	https://youtu.be/e52JM9JmX24
Synapse - Decentralized AI	Synapse	26-Oct-17	YouTube Video	https://youtu.be/Ms_1TZL-Z48
Introduction to Hyperledger Composer	Hyperledger	26-May-17	YouTube Video	https://youtu.be/cNvOQp8r0xo
Blockchain Expert Explains One Concept in 5 Levels of Difficulty WIRED	WIRED	28-Nov-17	YouTube Video	https://youtu.be/hYip_Vuv8J0
Ever wonder how Bitcoin (and other cryptocurrencies) actually work?	3Blue1Brown	7-Jul-17	YouTube Video	https://youtu.be/bBC-nXj3Ng4
How Bitcoin Works Under the Hood	CuriousInventor	14-Jul-13	YouTube Video	https://youtu.be/Lx9zgZCMqXE
How does a blockchain work - Simply Explained	Simply Explained Savjee	13-Nov-17	YouTube Video	https://youtu.be/SSo_EIwHSd4

Understand the Blockchain in Two Minutes	Institute for the Future (ITF)	18-Apr-16	YouTube Video	https://youtu.be/r43LhSUUGTQ
Supply Chain Provenance with Sawtooth	Sawtooth Lake	4-Apr-17	YouTube Video	https://youtu.be/-oxOas6cFXE
Tuna traceability recognition - English subtitled	BureauVeritasGroup	23-Nov-16	YouTube Video	https://youtu.be/2K7NJ1up-S0
Smart contracts - Simply Explained	Simply Explained Savjee	20-Nov-17	YouTube Video	https://youtu.be/ZE2HxTmxfrI
How blockchain is strengthening tuna traceability to combat illegal fishing	Joanna H. Warburton	22-Jan-18	YouTube Video	https://youtu.be/NitUDqusWzI
Jessi Baker: Blockchain Could Track your Fish Supper WIRED Retail WIRED	WIRED UK	7-Dec-15	YouTube Video	https://youtu.be/NCDhPfhWSig
How Blockchain Technology Can End Slavery In The Fishing Industry WWF-Australia	WWF-Australia	9-Jan-18	YouTube Video	https://youtu.be/oOywU_rXgFE
19 Industries the Blockchain Will Disrupt	Future Thinkers	15-Jun-17	YouTube Video	https://youtu.be/G3psxs3gyf8
All About Ethereum - Gas	AltcoinXP	7-Apr-17	YouTube Video	https://youtu.be/L3mlpwCgvtg
Programmer explains PoW vs PoS Blockchain	Ivan on Tech	6-May-17	YouTube Video	https://youtu.be/aRiUG2UeUBc
Decentralizing Everything with Ethereum's Vitalik Buterin Disrupt SF 2017	TechCrunch	18-Sep-17	YouTube Video	https://youtu.be/WSN5BaCzsbo
How the blockchain will radically transform the economy Bettina Warburg	TED	8-Dec-16	YouTube Video	https://youtu.be/RplnSVTzvnU

How Bitcoin Works in 5 Minutes (Technicak)	CuriousInventor	13-Apr-14	YouTube Video	https://youtu.be/I9jOJk30eQs
What is a service level agreement (SLA)?	Cyberpedia	n.d.	Web Article	https://www.paloaltonetworks.com/cyberpedia/what-is-a-service-level-agreement-sla
What is an API? In English, please.	Petr Gazarov	13-Aug-16	Web Article	https://medium.freecodecamp.org/what-is-an-api-in-english-please-b880a3214a82
Smart Contracts: The Blockchain Technology That Will Replace Lawyers	Blockgeeks	8-Jul-05	Web Article	https://blockgeeks.com/guides/smart-contracts/
Three common misconceptions about smart contracts	antonylewis2015	7-Mar-17	Blog	https://bitsonblocks.net/2017/03/07/three-common-misconceptions-about-smart-contracts/
Technical Introduction to Events and Logs in Ethereum	ConsenSys	6-Jun-16	Web Article	https://media.consenSys.net/technical-introduction-to-events-and-logs-in-ethereum-a074d65dd61e
An Introduction to Smart Contracts and Their Potential and Inherent Limitations	Skadden Arps Slate Meagher and Flom LLP	7-May-18	Web Article	https://www.lexology.com/library/detail.aspx?g=683fb3c1-dd6f-4daa-9fc7-dd43d44dcd24
In 'blockchain' technology, a futuristic solution to conservation's greatest challenges	Jennifer Morris	14-Aug-17	Web Article	https://blog.conservation.org/2017/08/in-blockchain-technology-a-futuristic-solution-to-conservations-greatest-challenges/
ethereum-studio-examples/contracts/WolframAlpha.sol	nyal	1-Mar-17	GitHub	https://github.com/oraclize/ethereum-studio-

					examples/blob/master/contracts/WolframAlpha.sol
Blockchain In: The Supply Chain Industry	Jacek Bastin		25-Feb-18	Web article	https://bitshouts.com/blockchain-supply-chain/
Best In Smart Contracts Nominees	Gold Token Awards 2018		n.d.	Website	https://www.goldentokenawards.com/best-in-smart-contracts-nominees-golden-token-awards
Contract 0xe083515D1541F2a9Fd0ca03f189F5D321C73B872	Fizzy		n.d.	Etherscan	https://etherscan.io/address/0xe083515d1541f2a9fd0ca03f189f5d321c73b872#code
An Overview of Non-fungible Tokens	Phil Glazer		1-Apr-18	Web Article	https://hackernoon.com/an-overview-of-non-fungible-tokens-5f140c32a70a
Storing documents in blockchain	Saurabh Gupta		2-Jun-17	Web Article	https://medium.com/blockchain-musings/storing-documents-in-blockchain-1d4d361ca962
The future of seafood is bait-to-plate transparency on the blockchain	Jessica McKenzie		25-Apr-18	Web Article	https://newfoodeconomy.org/blockchain-seafood-supply-chain-traseable-sea-quest-viant-wwf/
WWF develops blockchain solution to improve transparency in tuna industry	Yolanda Redrup		7-Jan-18	Web Article	https://www.afr.com/technology/wwf-develops-blockchain-solution-to-improve-transparency-in-tuna-industry-20180106-h0ejtb
Top Smart Contract Development Companies	n/a		n.d.	Web Article	https://www.goodfirms.co/directory/services/list-blockchain-

					technology-companies/smart-contract-development
A Guide to Smart Contracts and Their Implementation	Tania H.	n.d.	Web Article		https://rubygarage.org/blog/guide-to-smart-contracts
Anatomy of a Smart Contract	Steve Jones	14-Feb-17	Web Article		https://www.blockchain-expo.com/2017/02/blockchain/anatomy-smart-contract/
Ethereum's smart contracts are full of holes	Mike Orcutt	1-Mar-18	Web Article		https://www.technologyreview.com/s/610392/ethereums-smart-contracts-are-full-of-holes/
Blockchain Oracles	Blockchain Hub	n.d.	Web Article		https://blockchainhub.net/blockchain-oracles/
Blockchain Oracles Will Make Smart Contracts Fly	Doug von Kohorn	10-Mar-18	Web Article		https://hackernoon.com/oracles-help-smart-contracts-resolve-subjective-events-d81639d8291c
Microfinance 3.0: David Plattner on building an agro-blockchain for Africa	Monica Evans	27-May-18	Web Article		https://news.globallandscapesforum.org/27621/microfinance-3-0-david-plattner-on-building-an-agro-blockchain-for-africa/
How the blockchain could transform sustainability reporting	Russ Stoddard	24-Apr-18	Web Article		https://www.greenbiz.com/article/how-blockchain-could-transform-sustainability-reporting
How to use a Blockchain Explorer aka Blockexplorer	Isaac Rockett	9-Dec-17	Web Article		https://blockexplorer.com/news/use-blockchain-explorer-aka-blockexplorer/

Blockchain and the potential to help notoriously difficult industries	Laura Cox	4-Jan-18	Web Article	https://disruptionhub.com/smart-contract-uses/
Why Many Smart Contract Use Cases Are Simply Impossible	Gideon Greenspan	17-Apr-16	Web Article	https://www.coindesk.com/three-smart-contract-misconceptions/
How Oracles connect Smart Contracts to the real world	J Slobodnik	2-Feb-18	Web Article	https://medium.com/bethereum/how-oracles-connect-smart-contracts-to-the-real-world-a56d3ed6a507
How Do Ethereum Smart Contracts Work?	Alyssa Hertig	n.d.	Web Article	https://www.coindesk.com/information/ethereum-smart-contracts-work/
Can fiat money like USD be transferred via smart contracts in Ethereum?	user_default, Matthew Campbell, and ggtmtmgg	16-Nov-17	Question Forum	https://ethereum.stackexchange.com/questions/19286/can-fiat-money-like-usd-be-transferred-via-smart-contracts-in-ethereum

Appendix 3: Academic Papers Consulted for Exploratory Research

Smart contract specific academic papers were found by searching various smart contract terms in Solo and Google Scholar including “blockchain”, “smart contract” and “conservation AND blockchain OR smart contract”. Not each academic paper was cited in the body of this dissertation, but knowledge gained from this body of literature as a whole influenced the creation of the final smart contract model. A list of these papers can be found in the table below.

Appendix 3, Table 1: Complete list of academic smart contract papers consulted

Title	Date	Authors
Blockchain Contract: Securing a Blockchain Applied to Smart Contracts	2016	Watanabe et al.
Enlist blockchain to boost conservation	2017	Baynham-Herd
Crypto-control your own energy supply	2017	Andoni et al.
Formalizing and Securing Relationships on Public Networks	1997	Szabo
The green blockchain: Managing decentralized energy production and consumption	2017	Imbault et al.
Integration of IoT Devices via a Blockchain-based Decentralized Application	2017	Ahmad
The blockchain as a software connector	2016	Xu et al.
A Systematic Mapping Study on Current Research Topics in Smart Contracts	2017	Alharby and Moorsel
Auditing with Smart Contracts	2018	Rozario and Vasarhelyi

From Farm to Fork: How blockchain technology can be adopted in the meat industry for increased transparency and traceability	2017	Sander
A Blockchain Research Framework: What We (don't) Know, Where We Go From Here, and How We Will Get There	2017	Risius and Spohrer
Wise Contracts: Smart Contracts that Work for People and Machines	2017	Hazard and Haapio
Book-Smart, Not Street-Smart: Blockchain-Based Smart Contracts and the Social Workings of Law	2017	Levy
Blockchains and Smart Contracts for Internet of Things	2016	Christidis and Devetsikiotis
Blockchain technology innovations	2017	Ahram et al.
Validation and Verification of Smart Contracts: A Research Agenda	2017	Magazzeni et al.
Smart Contracts and the Cost of Inflexibility	2017	Sklaroff
IoT security: Review, blockchain solutions, and open challenges	2018	Khan and Salah
Formal Verification of Smart Contracts Based on Users and Blockchain Behaviors Models	2017	Abdellatif and Brousmiche
Blockchain's incompatibility for use as a land registry: issues of definition, feasibility and risk	2017	Thomas
Blockchain in government: Benefits and implications of distributed ledger technology for information sharing	2017	Olmes et al.
A survey on the security of blockchain systems	2018	Li et al.
Violable Contracts and Governance for Blockchain Applications	2017	Singh and Chopra

A Concurrent Perspective on Smart contracts	2017	Sergey and Hobor
Automated Execution of Financial Contracts on Blockchains	2017	Egelund-Müller et al.
Life Cycle of Smart Contracts in Blockchain Ecosystems	2017	Sillaber and Waltl
Making Smart Contracts Smarter	2016	Luu et al.
Cryptocurrencies, Smart Contracts, and Artificial Intelligence	2014	Omohundro
From Institutions to Code: Towards Automated Generation of Smart Contracts	2016	Frantz and Nowostawski
Improving data transparency in clinical trials using blockchain smart contracts	2016	Nugent et al.
The environment needs cryptogovernance	2017	Chapron
Blockchain could boost food security	2017	Ahmed and ten Brock
Blockchain moves to science	2017	Extance
Beyond bitcoin: an early overview on smart contracts	2017	Cuccuru
Smart contracts: terminology, technical limitations and real world complexity	2017	Mik
Is a 'smart contract' really a smart idea? Insights from a legal perspective	2017	Giancaspro
Evaluation of Logic-Based Smart Contracts for Blockchain Systems	2016	Idelberger et al.
Understanding the Blockchain Using Enterprise Ontology	2017	de Kruijff and Weigand
Where is Current Research on Blockchain Technology? - A Systematic Review	2016	Yli-Huumo et al.
Decentralized Blockchain-Based Electronic Marketplaces	2018	Subramanian
Blockchain Beyond Bitcoin	2016	Underwood

Blockchain	2017	Nofer et al.
Contract law 2.0: 'Smart' contracts as the beginning of the end of classic contract law	2017	Savelyev
Analyzing the bitcoin network: the first four years	2016	Lischke and Fabian

Appendix 4: White Papers Consulted for Exploratory Research

A total of 112 white papers were gathered during the exploratory research phase of this dissertation. They were collected from academic and non-academic articles that cited them, searching Google for “Smart Contract White Paper” and searching the Whitepaper Database for “Smart Contract” (<https://whitepaperdatabase.com/?s=smart+contract>). Additional conservation-specific smart contracts were found through personal communications with colleagues knowledgeable of the topic.

Appendix 4, Table 1: Complete list of white papers consulted

Title	Date	Authors	Company
Ethereum Alarm Clock Documentation	2017	Merriam	Ethereum Alarm Clock
Method and Apparatus to Enforce Smart Contract Execution Hierarchy on Blockchain	2016	Christidis, et al.	International Business Machines Corporation
FarmCoin Joint Venture Investor Presentation	2018	FinComEco and Block Commodities	Farm Coin
Smart City & Smart Planet Fund	2018	Not listed	SparkLabs
Tether: Fiat currencies on the Bitcoin blockchain	n.d.	Not listed	Tether
Veridium: The Natural Capital Marketplace: Leveraging Blockchain Technology to Create the World's First EcoSmart-Offset Token	2018	Not listed	Veridium
Carbon on Blockchain: Empowering people to save the planet with every purchase	2018	Not listed	Poseidon

Green List Standard Token (GLS): Fair Finances for Effective Conservation: A global green list of fairly and effectively managed protected areas successfully conserving nature	n.d.	Eyholzer et al.	Porini Foundation, IUCN, WWF Colombia, Nature Seychelles, Smartone.legal
AffiliateCoin White Paper: A decentralised affiliate network that uses Smart Contracts to create secure, indisputable transactions on the Blockchain	2017	Dodd et al.	AffiliateCoin
How Blockchain Technology Can Enhance EHR Operability	2016	Burniske et al.	ARK Invest & Gem
Arkadia Lending	n.d.	Not listed	Arkadia Lending
Bancor Protocol: Continuous Liquidity and Asynchronous Price Discovery for Tokens through their Smart Contracts; aka "Smart Tokens"	2017	Hertzog et al.	Bancor Protocol
Next generation agreements for everyone on the Ethereum Blockchain	n.d.	Mickel and Grasarevic	Contract Vault
CryptoKitties: Collectible and Breedable Cats Empowered by Blockchain Technology	n.d.	Not listed	CryptoKitties
DeepBrain Chain: Artificial Intelligence Computing Platform Driven by Blockchain	n.d.	Not listed	DeepBrain Chain
DENT: Tokenizing and Liberating the Mobile Data Market	2017	Not listed	DENT Wireless LTD
Dentacoin: The Blockchain Solution for the Global Dental Industry	2018	Not listed	Dentacoin
DOVU: How the World's First Mobility Cryptocurrency Will Create a Ubiquitous Reward Ecosystem for the Transport Industry	2018	Not listed	DOVU
Enigma: Decentralized Computation Platform with Guaranteed Privacy	n.d.	Zyskind et al.	Enigma

A Decentralised Sharing App running a Smart Contract on the Ethereum Blockchain	2016	Bogner et al.	ETH Zurich and University of St. Gallen
Etherparty: User-friendly Smart Contract Compiler	n.d.	Hobbs et al.	Etherparty
Blockchain in health: How distributed ledgers can improve provider data management and support interoperability	2016	Not listed	EY
Filecoin: A Decentralized Storage Network	2018	Protocol Labs	Filecoin
FlightDelay - the first decentralized Flight Delay Insurance on the Ethereum Blockchain	2017	christoph2806	FlightDelay
Crowdfund your prokect and start your ICO	n.d.	Not listed	FriendsFingers
Genesis Vision Whitepaper	2017	Nazarov et al.	Genesis Vision
ADEPT: An IoT Pracitioner Perspective	2015	Not listed	IBM
Empowering the edge: Practical insights on a decentralized Internet of Things	n.d.	Pureswaran et al.	IBM Institute for Business Value
iExec: Blockchain-Based Decentralized Cloud Computing	2018	Fedak et al	iExec
Blockchain-based Smart Tenancy Agreements	2017	Cuttel and Knottenbelt	Imperial College London
Formal Verification of Smart Contracts	2016	Bhargavan et al.	Inria, Microsoft Research and Harvard University
Intimate	2018	Not listed	Intimate
Bridging the gaps with Iolite blockchain	n.d.	Kuzminov et al.	Iolite Foundation

IPFS - Content Addressed, Versioned, P2P File System (Draft 3)	n.d.	Benet	IPFS
JOYSO Whitepaper: Hybrid Decentralized Token Exchange	2108	Not listed	JOYSO
Lance Chain	n.d.	Not listed	Lance Chain
Modum: Data integrity for supply chain operations, powered by blockchain technology	n.d.	Not listed	Modum
Nexo: The World's First Instant Crypto-backed Loans	n.d.	Not listed	Nexo, credissimo
Opus: Decentralized music distribution using InterPlanetary File Systems (IPFS) on the blockchain	2018	Jia et al.	Opus
Ox: An open protocol for decentralized exchange on the Ethereum blockchain	2017	Warren and Bandedali	OxProject
Whitepaper: Dapp for fair, p2p and trusted stock photography	n.d.	Stolberg et al.	photochain
Airswap (AST): A decentralised P2P protocol for 'swapping' ERC20 tokens	2017	Not listed	Piccolo Research
Populous Whitepaper: Invoice Finance on the Blockchain	n.d.	Williams	Populous
Storj: A Peer-to-Peer Cloud Storage Network	2016	Wilkinson et al.,	Storj
Welcome to the future: Terra Virtua White Paper	n.d.	Not listed	Terra Virtua
Formal Process Virtual Machine for Smart Contracts Verification	n.d.	Yang and Lei,	University of Electroci Science and Technology of China
Blockchain for Agriculture and Food	2017	Ge et al.	Wageningen University and TNO

Wagerr: The Decentralized Sportsbook of the Future Powered by Blockchain Technology	n.d.	Mah Christensen and Wagerr	
Waltonchain White Paper	2018	Not listed	Waltonchain
Xchange: "I need, you have, let's Xchange"	n.d.	Not listed	Xchange App
FOAM Whitepaper	2018	Not listed	Foamscape Corp
bioBIT Network	2018	Hilsberg et al.	bioBIT Network
Computer vision surveillance technology powered by fog network of miners	2018	Not listed	Faceter
DEEP AERO: The Drone People	2018	Not listed	DEEP AERO
The Zenome Project: Whitepaper: blockchain-based genomic ecosystem	2017	Kulemin et al.	The Zenome Project
Bringing Marine Archaeology to the Blockchain	2018	Not listed	PO8
Regen Network Whitepaper	2018	Booman et al.	Regen Network
Two Party double deposit trustless escrow in cryptographic networks and BitBay	n.d.	Zimbeck	BitBay
Blockchain's Smart Contracts: Driving the Next Wave of Innovation Across Manufacturing Value Chains	2016	Satyavolu Sangamnerkar and Cognizant	
Blockchain Technology: Beyond Bitcoin	2016	Crosby et al.	Google, Yahoo, Samsung Research America, and Fairchild Semiconductor
A Solution for the Problems of Translation and Transparency in Smart Contracts	2017	Khalil et al.	GRCTC

Building the Hyperconnected Future on Blockchains	2017	Gupta and ConsenSys LLC	Hexayurt.Capital and ConsenSys LLC
Architecture of the Hyperledger Blockchain Fabric	2016	Cachin	IBM
Applications of Blockchain Technology to Banking and Financial Sector in India	2017	DRBT	Institute for Development and Research in Banking Technology
Smart Contracts and Distributed Ledger - A Legal Perspective	2017	Not listed	ISDA and Linklaters
More Legal Aspects of Smart Contract Applications: Token Sales, Capital Markets, Supply Chain Management, Government and Smart Cities, Real Estate Registries, and Enabling Self-Sovereign Identity	2018	Hansen et al.	PerkinsCoie
Smarter Signatures: Experiments in Verifications	2016	Allen and Appelcline	Rebooting the Web of Trust Workshop
Enabling Trust on the Blockchain	2017	Shorish	Shorish Research
Distributed Ledgers, Smart Contracts, Business Standards and ISO 20022	2016	Not listed	SWIFT
Will That Smart Contract Really Do What You Expect It To Do?	2018	Everts and Muller	TNO
Scripting smart contracts for distributed ledger technology	2016	Seijas et al.	University of Kent and IOHK
Using Big Data to Detect Illegality in the Tropical Timber Sector: A Case Study of BVRio Due Diligence and Risk Assessment System	2016	Costa et al.	BVRIO
Agent-based Model of San Supply Governance Employing Blockchain Technology	2018	Pour et al.	Old Dominion University

ChainLink: A Decentralized Oracle Network	2017	Ellis et al.	ChainLink
Codium White Paper	n.d.	Not listed	Codium
Oraclize: A Scalable Architecture for On-Demand, Untrusted Delivery of Entropy	n.d.	Not listed	Oraclize
FAIZOD.BLOCKCHAIN - GPS Tracker	2017	Seifert	Faizod
The XY Oracle Network: The Proof-of-Origin Based Cryptographic Location Network	2018	Trouw et al.	XYO Network
Tron	n.d.	Not listed	Tron.Network
Aelf - A Multi-Chain Parallel Computing Blockchain Framework	2017	Not listed	AElf
AEternity blockchain: The trustless, decentralized and purely functional oracle machine	2017	Hess et al.	AEternity
Distributed Ledger Technology and Opportunities in Correspondent Banking	2016	Not listed	Anz and Wells Fargo
ARK Whitepaper: A Platform for Consumer Adoption	n.d.	Not listed	ARK
Asch: A decentralized application platform based on side-chain technology	n.d.	Not listed	Asch
Bitcoin: A Peer-to-Peer Electronic Cash System	2008	Nakamoto	Bitcoin
Corda: A distributed ledger	2016	Hearn	Corda
REM: Resource-Efficient Mining for Blockchains	n.d.	Zhang et al.	Cornell University, Cornell Tech, Jacobs Institute, Initiative for Cryptocurrencies & Contracts

Blockchain Application Builder for Ethereum dApps: No Coding Required	n.d.	Not listed	dApp Builder
Enjin Coin: Smart cryptocurrency for gaming	2017	Not listed	Enjin
EOS.IO Technical White Paper v2	2018	Gleehokie et al.	EOSIO
Ethereum White Paper: A Next Generation Smart Contract & Decentralized Application Platform	n.d.	Buterin	Ethereum
GoChain: Blockchain at Scale	n.d.	Not listed	GoChain
HTMLcoin White Paper	2017	Boncales et al.	HTMLcoin
Hyperledger Architecture, Volume I: Introduction to Hyperledger Business Blockchain Design Philosophy and Consensus	n.d.	Not listed	Hyperledger
Hyperledger Architecture, Volume II: Smart Contracts	n.d.	Not listed	Hyperledger
Sawtooth: An Introduction	2018	Olson et al.	Hyperledger
Smart Contracts. Real Property.	n.d.	Not listed	Mattereum
Nebulas Technical White Paper: The value-based blockchain operating system and search engine	2018	Not listed	Nebulas
A distributed network for the Smart Economy	n.d.	Not listed	NEO
Nuls - Proof of Credit (POC) Protocol	2017	Not listed	Nuls
OmiseGO: Decentralized Exchange and Payments Platform	2017	Poon and OmiseGo Team	OmiseGo

Smart-Contract Value-Transfer Protocols on a Distributed Mobile Application Platform	n.d.	Dai et al	Qtum Foundation and Large-Scale Systems Group
Ripio Credit Network: a global credit network based on cosigned smart contracts	n.d.	Not listed	Ripio International Limited
Lumino Transaction Compression Protocol (LTCP)	2017	Lerner	RSK
RSK: White paper Overview	2015	Lerner	RSK
Stratis Blockchain solutions: White paper	n.d.	Tew et al.	Stratis
Swarm Fund: Cooperative Ownership Platform for Real Assets	2017	Dietz et al.	Swarm
Unibright - the unified framework for based business integration	2018	Schmidt et al.	Unibright
Vechain: Development Plan and Whitepaper	2018	Not listed	Vechain
RIDE: a Smart Contract Language for Waves	2018	Begicheva and Smagin	Waves
WINGS: A project governance and backing platform with incentivized forecasting	2016	Popov et al.	WINGS
The Zilliqa Technical Whitepaper	2017	Not listed	Zilliqa

Appendix 5: List of Conservation Tools & Technology

Appendix 5, Table 1: The complete list of tools analysed for smart contract integration, including the tool category place in. Data collected from personal experience, presentations in the Technology Empowered Conservation Series presented at the University of Oxford, and from presentations at the iDigBio Digital Data in Biodiversity Research Conference.

Name	Tool Category
ArcGIS	Data Analysis
Jwatcher	Data Analysis
Predictive Analytics	Data Analysis
R	Data Analysis
Tableau	Data Analysis
SPSS	Data Analysis
Zooniverse	Data Analysis
Excel	Data Storage & Management
Tablet data collection apps	Data Capture
Fulcrum	Data Capture
Sensors (temperature, wind, etc)	Data Capture

Scales	Data Capture
Robotics	Data Capture
AudioMoth	Data Capture
Remote Control Photography/Video	Data Capture
Drones	Data Capture
Doves	Data Capture
Infrared	Data Capture
Terrestrial Lasor Scanning	Data Capture
Lidar	Data Capture
Open Vertebrate Thematic Collections Network	Data Capture
3D Digital Life Project	Data Capture
Trail Cameras	Data Capture
IoT enabled cameras	Data Capture
GoogleLens	Data Analysis

LepSnap	Data Analysis
Cybertracker	Data Capture
SIM Collars for Text Messaging	Monitoring & Tracking
Fitbits	Data Capture
iNaturalist	Information Platform & Database
Machine Learning, Deep Learning, NLP, AI	Prediction
IoT	Data Storage & Management
Photogrammetry	Data Analysis
Internal Databases and Excel Spreadsheets	Data Storage & Management
Google Drive	Data Storage & Management
Cloud Storage	Data Storage & Management
GPS	Monitoring & Tracking
DataWeb	Data Storage & Management
NSF	Fund Raising & Financial Flow
Crowdfunding	Fund Raising

Gene Sequencing	Data Analysis
Visipedia	Data Analysis
IoT and machine learning field cameras	Data Capture
NatureVest	Fund Raising & Funding Flow
Google Earth	Information Platform & Open Database
Drone Sampling	Data Capture
Smart Traps	Data Capture
3D Printing	N/A
Github	Information Platform & Open Database
ARBIMON II Bio-acoustic Analysis Web Platform	Data Analysis
Movebank	Data Analysis
Scratchpads	Information Platform & Open Database
iPlant collaborative	Information Platform & Open Database
Natura 2000 Viewer	Information Platform & Open Database
Publications	Information Platform & Open Database

WolframAlpha	Information Platform & Open Database
Half-Earth Project	Information Platform & Open Database
EcoSys	Information Platform & Open Database
BIOWEB Ecuador	Information Platform & Open Database
Twitter	Information Platform & Open Database
Instagram	Information Platform & Open Database
Facebook	Information Platform & Open Database
Email	Data Storage & Management
Wildlabs.net	Information Platform & Open Database
Dragonfly	Data Analysis
iDigBio	Information Platform & Open Database
GBIF	Information Platform & Open Database
Biodiversity Heritage Library	Information Platform & Open Database
Encyclopedia of Life	Information Platform & Open Database
Predicts.org.uk	Information Platform & Open Database
Global Biotic Interactions database	Information Platform & Open Database

GenBank	Information Platform & Open Database
Species+	Information Platform & Open Database
Catalogue of Life	Information Platform & Open Database
Oxford Research Archive	Information Platform & Open Database
Notes from Nature	Information Platform & Open Database
eBird	Information Platform & Open Database
GROMS	Information Platform & Open Database
OCTOPUS	Information Platform & Open Database
Atlas of Living Australia	Information Platform & Open Database
SlideAtlas	Information Platform & Open Database
Natural History Museum Databases	Information Platform & Open Database
Morpho Source	Information Platform & Open Database
Phenoscape.org	Information Platform & Open Database
Map of Life	Information Platform & Open Database
Antweb	Information Platform & Open Database
obofoundry.org	Information Platform & Open Database

NSF Arctic Data Center	Information Platform & Open Database
DataOne Network	Information Platform & Open Database
SEINet	Information Platform & Open Database
Oregonflora.org	Information Platform & Open Database
Arctos	Information Platform & Open Database
CalAdapt	Information Platform & Open Database
Holos	Information Platform & Open Database
Reserve Mapper	Information Platform & Open Database
VertNet	Information Platform & Open Database
GEO BON	Information Platform & Open Database
iBird	Information Platform & Open Database
Project Noah	Information Platform & Open Database
World Database of Protected Areas	Information Platform & Open Database
Global Forest Watch	Information Platform & Open Database
Barcode of Life Database	Information Platform & Open Database
Earth on AWS	Information Platform & Open Database

MapBiomias		Information Platform & Open Database
EcoEngine		Information Platform & Open Database
sketchfab		Information Platform & Open Database
The Living Atlas of the World		Information Platform & Open Database
Google Earth Engine		Information Platform & Open Database
NASA Images		Information Platform & Open Database
Global Fishing Watch		Information Platform & Open Database
Agent-based modeling		Prediction
NetLogo		Prediction
Groupget		Fund Raising & Funding Flow
Python		N/A
SMART Collars		Data Capture
LEFT		Report Generation
Ecoset		Report Generation
InVEST		Report Generation
NaturETrade		Report Generation

Natural Capital Report Generation
Planning Tool

WWF-SIGHT	Report Generation
ARBIMON	Data Capture
Ecological Acoustic Recorders	Data Capture
RFID	Monitoring & Tracking
QR Code	Monitoring & Tracking
Virtual Reality	N/A

Appendix 6: Sample Interview Questions

Smart Contract Developer Questions:

1. Do you know of any cases of smart contracts used for biodiversity or conservation?
2. Do you know of any cases of smart contracts being used to verify goal outcomes to be true?
3. Can you tell me about any limitations to what data can be connected to oracle services?
4. Can you tell me about any limitations to what can be used as triggering events?
5. How does your company approach data security?
6. How does your company approach smart contract errors?
7. Is it possible to use smart contracts to generate reports?
8. What do you see for the future of smart contracts?

EWB Questions:

1. What are the overall goals of EWB?
2. How do you measure if these goals have been reached?
3. How are individual animals and herd tracked?
4. How is breeding tracked?
5. What tools and technologies are used to do this?
6. Does EWB collect any data considered sensitive?
7. How is this information reported?
8. To whom is this information reported?
9. Are there any areas of EWB operations that you have identified that are in need of improvement?
10. Are there any EWB operations that you think could benefit from automation?
11. Does EWB offer a return on investment?
12. What information would you include in a “feel good story”?
13. How do you think EWB could attract investment?

Conservation Investment Consultant Questions:

1. What contributes to an investor’s decision to invest in a company or project?
2. What information would an impact investor need to feel as though they’ve achieved a non-financial ROI?
3. How are investors updated in non-financial ROI and how is this information managed?
4. Is there a general interest in tokenising or cryptocurrencies?

Appendix 7: List of Smart Contract Companies Contacted

Lisk	Corda	Intellectsoft	Distylics	Eos
Neo	Smart Contract	OpenXCell	Ethereum	CryptoKitties
Sagewise	Oraclize	Appinventiv	RSK	GainForest
Etherparty	Hyperledger	Consenys	Leeway Hertz	Porini Foundation
Intimate	Block.one			

Rewilding Europe

European Wildlife Bank (EWB)

Smart Contract Use Cases

Smart contracts are written in “If, then, else” format. “If” is defined as a triggering event, or a specified condition, such as a date. “Then” is the action that will be fulfilled if the condition is met. “Else” is what occurs if the condition is not met. An oracle is a service that connects data not on a blockchain to smart contracts. This is an automated process controlled by the smart contract code.

1: Herd Tokenisation

Purpose: To attract investors, track herd divisions, aid storytelling, and provide a potential financial return on investment

Details:

- Each herd would be assigned a virtual token code which would be traceable on a blockchain. The token’s code could contain information about the herd species, starting number of animals in a herd, an identification number, etc.
- At the end of each loan period, if half of the herd is returned to EWB, a new token is created. These tokens would contain information similar to the original token code and would also include the identification number of the original herd. This allows traceability of herd divisions and growth over time.
- The token would be digitally transferred to an investor and could represent a herd that an investor “owns.” Tokenising herds would enable investors to trade or sell herd tokens to other investors. This would enable investors to gain an external financial return on investment based on the market evaluation of the token. Investors would also be able to trade with another investor to “own” a different herd. Because the tokens exist on a blockchain, each token is secure and traceable, preventing fraud.
- Relaying information or “feel good stories” to investors could then be based on token, meaning only the owner of a specific herd token would gain information about that herd. This aspect would then create a market for herd “feel good stories.” For example, herd tokens could be purchased as a gift for other individuals. Because each token represents a specific herd defined in the unique code, this creates rarity and an incentive to invest in EWB.

“If, then, else” example:

Transfer of token from EWB:

If Investor A submits funds,

Then Herd Token A transfers to Investor A, funds transfer to EWB,

Else Investor A refunded.

Transfer of token between investors:

If Investor B submits funds,

Then Herd Token A transfers to Investor B, funds transfer to

Investor A,

Else Investor B refunded.

Herd token creation:

If new herd created (via oracle connected to database or triggered by a herd loan smart contract [see below]),

Then Herd Token B created and transferred to EWB,

Else nothing.

Technological Limitations: I believe there is a way to grant access to a closed blockchain based on token ownership, and this could be automated with smart contracts. However, I need to read a little more to understand if this is technologically possible or not. Funds transferred using smart contracts must be a cryptocurrency, else an oracle will need to be used to automate the transfer of a fiat (euros, pounds, dollars, etc) to a cryptocurrency and back again.

Rewilding Europe Limitations: EWB will need to enable an oracle to connect to their databases. This can be done in a way that encrypts data to increase security. I believe this process can be offline using oracle hardware, however, a database may need to be stored online using a cloud service.

2: Herd Loan

Purpose: To automate notifications, track herd relocation and veterinary documentation, track herd ownership, and generate new Herd Tokens

Details:

- Aspects of a herd loan contract could be automated using smart contracts.
- In order for the contract to be signed, a herd manager could provide proof that their land meets the requirements of EWB, including land size, right to graze, water availability, fencing, and proof of insurance, if desired. This information would be shared on a blockchain by herd managers.
- Once this information was confirmed to be on a blockchain, a smart contract would allocate a herd identification code, identical to a Herd Token code, to the herd manager.
- At this point, EWB, the herd manager, and an animal transportation company are automatically notified to schedule herd movement.
- At each step of herd movement, EWB and the herd manager are automatically notified. Movements include loading and unloading a vehicle and can be updated using Internet of Things and scanning an animal in the herd or through manual entry into a database which is connected to a smart contract using an oracle.
- Veterinary documents can also be uploaded onto the blockchain and notifications can be automatically sent to EWB and herd managers to update parties on the status of animal health during movement.
- If desired, a payment aspect can be incorporated into this process which would automatically distribute payment from EWB to animal movement companies and veterinarians when proof of completion is provided.
- At a set interval during the loan period, a smart contract could update EWB and herd managers of herd size by connecting a database to an oracle.
- Alternatively, a smart contract could be used to notify both EWB and herd managers to collect herd size information at set periods of time.
- Smart contracts could also be used at the end of a loan period. If connected to a database, a smart contract could notify EWB and herd managers of the number of animals and the age and gender ratios that must be returned to EWB based on the final herd size. A herd manager would then decide to return the animals to EWB, triggering notifications to the transportation company and the creation of a new Herd Token and herd identification number, or keep the animals by providing proof of increased land size, triggering a new loan smart contract.
- The Herd Token owner would be automatically notified of herd growth.
- If the loan is prematurely cancelled, the smart contract could be automatically terminated when a database is updated via oracle connection.

“If, then, else” example:

```
If Herd Manager uploads documentation to blockchain,  
    Then transfer Herd Code to Herd Manager, return "true",  
    Else nothing.  
        If "true",  
            Then notify for herd movement, transfer EWB movement  
            funds to smart contract,  
            Else nothing.  
        If movement company scans animal (connected to Internet of  
        Things or oracle)  
            Then half of funds transferred to company, notify,  
            Else refund EWB, notify.  
    If veterinarian uploads documents to blockchain,  
        Then transfer funds to veterinarian, notify,  
        Else refund EWB, notify.  
    If movement company scans animal at X location (connected to  
    Internet of Things or oracle),  
        Then transfer remaining funds to company, notify,  
        Else refund EWB, notify.  
    If veterinarian uploads documents to blockchain,  
        Then transfer funds to veterinarian, notify,  
        Else refund EWB, notify.  
    If Herd Token A is held,  
        Then notify Token A holder of movement,  
        Else nothing.  
    If July 14th 2019 (yearly date is monitored by oracle connected to  
    calendar),  
        Then publish herd information to blockchain (via oracle connected  
        to database),
```

Else nothing.

 If 2019 herd is greater than 2018 herd,

 Then return "true", notify,

 Else return "false", notify.

 If Herd Token A is held,

 Then notify Token A holder of herd growth,

 Else nothing.

If July 14th 2023 (final contract date monitored by oracle connected to calendar),

 Then publish herd information to blockchain (via oracle connected to database),

 Else nothing.

 If 2023 herd size is greater than or equal to 2018 herd size,

 Then return 2023 herd size divided by 2, notify,

 Else return 2018 herd size, notify.

If Herd Manager uploads increased land documentation to blockchain,

 Then create new smart contract, notify,

 Else notify animal movement company and issue Herd Token B to EWB.

 If Herd Token A is held,

 Then notify Token A holder of decision,

 Else nothing.

If contract is terminated (via oracle connected to database),

 Then notify animal movement company, end smart contract,

 Else nothing.

 If Herd Token A is held,

 Then notify Token A holder of cancellation,

 Else nothing.

Technological Limitations: Blockchains can only store a limited amount of information. This case would require land and grazing right documentation as well as veterinary reports to be shared. I will need to read further into how documents can be stored on a blockchain or if an encrypted document sharing service connected to a blockchain is more appropriate for this use.

Rewilding Europe Limitations: Information from herd managers regarding herd size must be known to be true and this information must be shared in a database accessible by an oracle, such as a database stored in a cloud or oracle hardware. Animal movement companies must be able to scan at least one animal or enter information immediately into a cloud database to automatically update the smart contract on animal movement.

3: Proof of Goal Achievement

Purpose: To automate “feel good stories” and provide proof of goal achievement

Details:

- Smart contracts could automate some data analysis and photo sharing to prove goal achievement. This would involve using Internet of Things and oracle services to connect databases and other data sources to smart contracts to automate notifications, basic data analysis at set intervals, and instantly send images and progress to investors.
- Data sources might include an EWB database stored in a cloud or connected to a hardware oracle, images taken from field cameras and professional photographers, or satellite images taken from such databases as Google Earth Engine or NASA Earthdata.
- Animal images can prove herd existence and reproduction while satellite imagery can prove land change over time.
- Automatically updating investors on goal achievement would increase the number of reports an investor receives each year with no extra work for EWB.

“If, then, else” example:

Google Earth Engine:

If the date is 14th July 2019 (yearly date monitored via oracle service monitoring a calendar),

Then connect to Google Earth Engine for X location range (connection via oracle service),

Else do nothing.

If satellite image is available (monitored via oracle service),

Then return percent land change to 2018 land and return image to blockchain (analysis by oracle service),

Else return "error", notify.

If percent change is greater than or equal to 5%,

Then return "true", notify,

Else return "false", notify.

If Herd Token A is held,

Then send information to Token A holder,

Else nothing.

If the date is 14th July 2023 (final contract date monitored via oracle service monitoring a calendar),

Then return time series video to blockchain (connection and creation via oracle service and Google Earth Engine), notify,

Else return "error", notify.

If Herd Token A is held,

Then send video to Token A holder,

Else nothing.

Trail camera images:

If image is stated to contain a desired species (via oracle connected to EWB image database),

Then send image to Herd Token A holder,

Else nothing.

(This process could be further automated with the use of trail cameras that are connected to Internet of Things)

Technological Limitations: Because images and large files cannot be stored in a smart contract, the images would be stored directly on a blockchain either as a full file or in partnership with a decentralised image sharing platform for blockchains. Smart contracts would only be used to notify individuals that images are available or use an oracle to send the image to an investor's email. This would require email encryption for security. Using Google Earth Engine or NASA Earthdata for land change analysis or the creation of a time series video would require more discussion with developers to fully understand the limitations of this. Image recognition can be done via three ways: automated with machine learning, using a crowdsourcing platform like Zooniverse, or

manually by EWB employees. With the first option, a smart contract can be linked directly to the device, but would require artificial intelligence training of the specific species in EWB and the purchase of devices capable of this. Automating image uploading to Zooniverse would require purchasing devices connected to Internet of Things. Manual image recognition by EWB employees or manual uploading to Zooniverse would require physical contact with devices.

Rewilding Europe Limitations: Automated image detection or upload to Zooniverse requires Internet of Things enabled trail cameras. Land change analysis using satellite images may require knowledge of percent change desired.

4: *Funding Flow*

Purpose: To prove transparency and traceability of EWB funds

Details:

- Distributing funds is a common smart contract use case. It enables conditional release of funds with automated refunds if conditions are not met by a specified time period.
- This would enable investors to release funds to EWB based on completion of certain goals or based on transfer of Herd Token ownership.
- It would also enable EWB to release funds to animal movement companies and veterinarians based on work completion or document sharing.
- EWB might also use smart contracts to distribute funds to photographers based on photo sharing, to other companies based on promotional materials creation, to purchase equipment, or to pay EWB employees.
- Because smart contracts are stored on a blockchain, investors will be able to see what EWB spends funds on and who EWB works with.

“If, then, else” example:

Professional Photographer Payments:

If images are shared by photographer to blockchain by X date (date monitored by oracle),

Then transfer funds from EWB to photographer,

Else refund EWB.

(A specific date can be set and either EWB will be refunded if photographs are not uploaded by the set date. EWB can also use a smart contract to reduce the funds transferred to a photographer based on number of days past the deadline the photographer shares images. This might be a percent fund decrease per week overdue)

Technological Limitations: Smart contracts must use a cryptocurrency to automatically move funds. It is possible to use fiat (euros, pounds, dollars, etc), however, an oracle must be involved to contact banks, which will not be an automatic process. It is also possible to transfer a cryptocurrency into Euros by connecting to a trading platform, such as Coinbase, which can be automated. This will add another step to the smart contract and requires a market for the cryptocurrency that is used. The use of a popular cryptocurrency (i.e. Bitcoin or Ether) would enable smoother transactions as a market already exists for these cryptocurrencies. A new cryptocurrency (i.e. Wildcoin) would be more difficult to transfer to a fiat on an existing trading platform. Alternatively, EWB can enable transfer from fiat to a created cryptocurrency on an EWB created investor platform, which can be an automated process.

Rewilding Europe Limitations: EWB would need to create or use an existing cryptocurrency. EWB may need to enable transfer from a newly created cryptocurrency to a fiat.

Appendix 9: Full List of White Paper Adaptability

Appendix 9, Table 1: Potential of underlying technology described in each white paper to be applied to potential conservation-specific smart contracts

Title	Company	Potential Conservation Application
Ethereum Alarm Clock Documentation	Ethereum Alarm Clock	Enables future smart contract execution if using Ethereum
Method and Apparatus to Enforce Smart Contract Execution Hierarchy on Blockchain	International Business Machines Corporation	Enables priority level to be set for conservation smart contracts
FarmCoin Joint Venture Investor Presentation	Farm Coin	Tokenises agricultural yields and allows for groups that normally can't get investments to gain investments
Smart City & Smart Planet Fund	SparkLabs	This could be used to facilitate and distribute investment in conservation projects
Tether: Fiat currencies on the Bitcoin blockchain	Tether	A 1 to 1 fiat-cryptocurrency exchange rate could decrease volatility, appealing to conservation projects
Veridium: The Natural Capital Marketplace: Leveraging Blockchain Technology to Create the World's First EcoSmart-Offset Token	Veridium	Carbon offsetting token is directly related to conservation
Carbon on Blockchain: Empowering people to save the planet with every purchase	Poseidon	Carbon offsetting token is directly related to conservation
Green List Standard Token (GLS): Fair Finances for Effective Conservation: A global green list of fairly and effectively managed protected areas successfully conserving nature	Porini Foundation, IUCN, WWF Colombia, Nature Seychelles, Smartone.legal	This is directly related to conservation
AffiliateCoin White Paper: A decentralised affiliate network that uses Smart Contracts to create secure, indisputable transactions on the Blockchain	AffiliateCoin	Not applicable
How Blockchain Technology Can Enhance EHR Operability	ARK Invest & Gem	Connection to fitness devices like Fitbits could be applicable for conservation ecotourism incentives and rewards
Arkadia Lending	Arkadia Lending	Enables investors to sell/trade investments to/with one another. This could be used in conservation for selling/trading investments or tokens

Bancor Protocol: Continuous Liquidity and Asynchronous Price Discovery for Tokens through their Smart Contracts; aka "Smart Tokens"	Bancor Protocol	Allows investors to trade conservation token with other tokens
Next generation agreements for everyone on the Ethereum Blockchain	Contract Vault	Smart contract templates enable conservation workers with no coding experience to create smart contracts
CryptoKitties: Collectible and Breedable Cats Empowered by Blockchain Technology	CryptoKitties	Great model for tokenising herds or species with non-fungible tokens that can be sold or traded. Digital scarcity creates a market place for tokens
DeepBrain Chain: Artificial Intelligence Computing Platform Driven by Blockchain	DeepBrain Chain	Could be used to distribute computing power for things that need AI and very large datasets
DENT: Tokenizing and Liberating the Mobile Data Market	DENT Wireless LTD	Not applicable
Dentacoin: The Blockchain Solution for the Global Dental Industry	Dentacoin	Could be adapted to permanently store conservation NGO reviews
DOVU: How the World's First Mobility Cryptocurrency Will Create a Ubiquitous Reward Ecosystem for the Transport Industry	DOVU	This is an example of IoT-enabled devices used with smart contract and a reward system
Enigma: Decentralized Computation Platform with Guaranteed Privacy	Enigma	This technology is necessary for storing files on a blockchain
A Decentralised Sharing App running a Smart Contract on the Ethereum Blockchain	ETH Zurich and University of St. Gallen	Could be used to share conservation tools/tech with scientists to decrease cost of buying (enable renting scientific tools/tech)
Etherparty: User-friendly Smart Contract Compiler	Etherparty	Smart contract templates enable conservation workers with no coding experience to create smart contracts
Blockchain in health: How distributed ledgers can improve provider data management and support interoperability	EY	This use would be applicable in sharing data across the conservation network or between NGOs
Filecoin: A Decentralized Storage Network	Filecoin	Not applicable
FlightDelay - the first decentralized Flight Delay Insurance on the Ethereum Blockchain	FlightDelay	Could be applicable in conservation when there are multiple outcomes that could occur depending on the condition met and also could be used to distribute funds based on a time period
Crowdfund your project and start your ICO	FriendsFingers	Could be used to crowdfund conservation projects

Genesis Vision Whitepaper	Genesis Vision	An example of how a conservation token could be exchanged for fiat through a centralised platform. This type of DApp is an example of attracting investors with an easier transfer to a cryptocurrency from fiat and back again
ADEPT: An IoT Pracioner Perspective	IBM	Not included in analysis
Empowering the edge: Practical insights on a decentralized Internet of Things	IBM Institute for Business Value	Conservation tools and technology that are IoT-enabled can be connected to a blockchain
iExec: Blockchain-Based Decentralized Cloud Computing	iExec	Could be used to decrease computational power required for large computations
Blockchain-based Smart Tenancy Agreements	Imperial College London	Multiple applications
Formal Verification of Smart Contracts	Inria, Microsoft Research and Harvard University	Only applicable if conservation workers are familiar with F*
Intimate	Intimate	Enables reputation rating based on smart contract transaction history/good participation and ID verification. A good example of an easy to understand user interface
Bridging the gaps with Iolite blockchain	Iolite Foundation	Only applicable if conservation workers are familiar with coding languages
IPFS - Content Addressed, Versioned, P2P File System (Draft 3)	IPFS	Enables large file sharing in a decentralised way across a network with keys that only enable specific individuals to access images/videos/large files
JOYSO Whitepaper: Hybrid Decentralized Token Exchange	JOYSO	Enables conservation token exchange to other tokens
Lance Chain	Lance Chain	Could be used directly to hire freelancers for conservation projects
Modum: Data integrity for supply chain operations, powered by blockchain technology	Modum	Primarily applicable in supply chain management so for sustainability and knowing that something has come from where it says it has. Also applicable for animal transport to prove ownership change
Nexo: The World's First Instant Crypto-backed Loans	Nexo, credissimo	Applicable for conservation loans that include a monetary return on investment/loan
Opus: Decentralized music distribution using InterPlanetary File Systems (IPFS) on the blockchain	Opus	Decentralised large file distribution
Ox: An open protocol for decentralized exchange on the Ethereum blockchain	OxProject	Enables conservation and non-conservation token exchange.
Whitepaper: Dapp for fair, p2p and trusted stock photography	photochain	Conservation application includes file access transfer using IPFS
Airswap (AST): A decentralised P2P protocol for 'swapping' ERC20 tokens	Piccolo Research	Enables conservation token exchange to other tokens

Populous Whitepaper: Invoice Finance on the Blockchain	Populous	Could enable conservation loans
Storj: A Peer-to-Peer Cloud Storage Network	Storj	Enables large file sharing in a decentralised way across a network with keys that only enable specific individuals to access images/videos/large files
Welcome to the future: Terra Virtua White Paper	Terra Virtua	Could be applicable in gamified conservation applications
Formal Process Virtual Machine for Smart Contracts Verification	University of Electroci Science and Technology of China	Could be used to verify that smart contracts are secure and reliable
Blockchain for Agriculture and Food	Wageningen University and TNO	Use in supply chain, sharing certifications, and following location movement of animals
Wagerr: The Decentralized Sportsbook of the Future Powered by Blockchain Technology	Wagerr	Not applicable
Waltonchain White Paper	Waltonchain	IoT-enabled connectivity
Xchange: "I need, you have, let's Xchange"	Xchange App	SMS notifications could be useful for conservation
FOAM Whitepaper	Foamscape Corp	Connects geolocation data to conservation smart contracts
bioBIT Network	bioBIT Network	Directly related
Computer vision surveillance technology powered by fog network of miners	Faceter	Potential use to recognise species or individuals or even poaching in decentralised web of connected cameras
DEEP AERO: The Drone People	DEEP AERO	Potential use in coordination of conservation drones
The Zenome Project: Whitepaper: blockchain-based genomic ecosystem	The Zenome Project	Potential use in storing large species genomic files and potential to buy/sell genetic information
Bringing Marine Archaeology to the Blockchain	PO8	Potential use in tracking ownership/location of museum specimens
Regen Network Whitepaper	Regen Network	Directly related
Two Party double deposit trustless escrow in cryptographic networks and BitBay	BitBay	Enables conservation token exchange to other tokens.
Blockchain's Smart Contracts: Driving the Next Wave of Innovation Across Manufacturing Value Chains	Cognizant	Not included in analysis

Blockchain Technology: Beyond Bitcoin	Google, Yahoo, Samsung Research America, and Fairchild Semiconductor	Not included in analysis
A Solution for the Problems of Translation and Transparency in Smart Contracts	GRCTC	Not included in analysis
Building the Hyperconnected Future on Blockchains	Hexayurt.Capital and ConsenSys LLC	Not included in analysis
Architecture of the Hyperledger Blockchain Fabric	IBM	Not included in analysis
Applications of Blockchain Technology to Banking and Financial Sector in India	Institute for Development and Research in Banking Technology	Not included in analysis
Smart Contracts and Distributed Ledger - A Legal Perspective	ISDA and Linklaters	Not included in analysis
More Legal Aspects of Smart Contract Applications: Token Sales, Capital Markets, Supply Chain Management, Government and Smart Cities, Real Estate Registries, and Enabling Self-Sovereign Identity	PerkinsCoie	Not included in analysis
Smarter Signatures: Experiments in Verifications	Rebooting the Web of Trust Workshop	Not included in analysis
Enabling Trust on the Blockchain	Shorish Research	Not included in analysis
Distributed Ledgers, Smart Contracts, Business Standards and ISO 20022	SWIFT	Not included in analysis
Will That Smart Contract Really Do What You Expect It To Do?	TNO	Not included in analysis
Scripting smart contracts for distributed ledger technology	University of Kent and IOHK	Not included in analysis
Using Big Data to Detect Illegality in the Tropical Timber Sector: A Case Study of BVRio Due Diligence and Risk Assessment System	BVRIO	Record management in decentralised transparent way
Agent-based Model of San Supply Governance Employing Blockchain Technology	Old Dominion University	Agent-based modeling could be used to predict how agents would interact on a blockchain prior to developing a blockchain network
ChainLink: A Decentralized Oracle Network	ChainLink	Oracle services are necessary for outside world connection

Codium White Paper	Codium	Oracle services are necessary for outside world connection
Oraclize: A Scalable Architecture for On-Demand, Untrusted Delivery of Entropy	Oraclize	Oracle services are necessary for outside world connection
FAIZOD.BLOCKCHAIN - GPS Tracker	Faizod	Connects geolocation data to blockchain
The XY Oracle Network: The Proof-of-Origin Based Cryptographic Location Network	XYO Network	Connects geolocation data to blockchain and smart contracts
Tron	Tron.Network	Necessary in large file sharing
Aelf - A Multi-Chain Parallel Computing Blockchain Framework	AElf	Enables a conservation blockchain to be connected to other blockchains
AEternity blockchain: The trustless, decentralized and purely functional oracle machine	AEternity	Low energy cost blockchain
Distributed Ledger Technology and Opportunities in Correspondent Banking	Anz and Wells Fargo	Enables a conservation blockchain to be connected to other blockchains
ARK Whitepaper: A Platform for Consumer Adoption	ARK	Potential blockchain platform
Asch: A decentralized application platform based on side-chain technology	Asch	Could be adapted for a conservation network with sidechains for different NGOs
Bitcoin: A Peer-to-Peer Electronic Cash System	Bitcoin	Not applicable
Corda: A distributed ledger	Corda	Blockchain with zip file transfer
REM: Resource-Efficient Mining for Blockchains	Cornell University, Cornell Tech, Jacobs Institute, Initiative for CryptoCurrencies & Contracts	Lower energy blockchain
Blockchain Application Builder for Ethereum dApps: No Coding Required	dApp Builder	Smart contract templates
Enjin Coin: Smart cryptocurrency for gaming	Enjin	Not applicable
EOS.IO Technical White Paper v2	EOSIO	Decreases blockchain storage computational cost
Ethereum White Paper: A Next Generation Smart Contract & Decentralized Application Platform	Ethereum	Conservation can build a DApp on the Ethereum blockchain

GoChain: Blockchain at Scale	GoChain	Decreases blockchain storage computational cost
HTMLcoin White Paper	HTMLcoin	Applicable blockchain backbone
Hyperledger Architecture, Volume I: Introduction to Hyperledger Business Blockchain Design Philosophy and Consensus	Hyperledger	Not included in analysis
Hyperledger Architecture, Volume II: Smart Contracts	Hyperledger	Not included in analysis
Sawtooth: An Introduction	Hyperledger	Conservation can build a DApp on the Hyperledger blockchain
Smart Contracts. Real Property.	Mattereum	Can write natural language contracts that connect to smart contract code to ease understanding/creation of smart contracts
Nebulas Technical White Paper: The value-based blockchain operating system and search engine	Nebulas	Enables smart contract searching
A distributed network for the Smart Economy	NEO	Enables smart contracts written in regular coding languages
Nuls - Proof of Credit (POC) Protocol	Nuls	Potential use of requiring ownership of a token to access the blockchain network
OmiseGO: Decentralized Exchange and Payments Platform	OmiseGo	Could enable cross blockchain exchange of tokens, and use of a fiat-backed token to decrease volatility
Smart-Contract Value-Transfer Protocols on a Distributed Mobile Application Platform	Qtum Foundation and Large-Scale Systems Group	Blockchain platform
Ripio Credit Network: a global credit network based on cosigned smart contracts	Ripio International Limited	Not applicable
Lumino Transaction Compression Protocol (LTCP)	RSK	Not included in analysis
RSK: White paper Overview	RSK	Blockchain platform that could be used.
Stratis Blockchain solutions: White paper	Stratis	A conservation blockchain network platform could facilitate the exchange of a cryptocurrency to fiat
Swarm Fund: Cooperative Ownership Platform for Real Assets	Swarm	Enables smart contract visualisation to ease understanding
Unibright - the unified framework for based business integration	Unibright	Automated smart contract generation is useful in conservation due to limited smart contract knowledge within the field

Vechain: Development Plan and Whitepaper	Vechain	Not applicable
RIDE: a Smart Contract Language for Waves	Waves	Not applicable
WINGS: A project governance and backing platform with incentivized forecasting	WINGS	Could be used in crowdfunding
The Zilliqa Technical Whitepaper	Zilliqa	Allows for multiple smart contracts to be executed simultaneously

Appendix 10: Smart Contract Limitations and Suggested Solutions

Limitation	Description of problem	Solution	Sources
Adoption of technology may be limited	<ul style="list-style-type: none"> • Requires high bandwidth for blockchain development • May require access to expensive software and hardware • Requires coding knowledge 	<ul style="list-style-type: none"> • User-friendly interfaces such as code visualization tools, smart contract templates, autogeneration • Alerts and notifications • Physical cards for token payment • Automated plain-language blockchain report • Extraction of information directly into an Excel document 	(Genesis Vision; Imperial College London; Nexo and Credissimo; OmiseGo International Limited; Photochain; Ripio; Stratis; Terra Virtua; Tether; VeChain; Xchange App; FlightDelay; BitBay; JOYSO; OxProject; Picolo Research; Porini Foundation; Egelund-Müller et al., 2017; Conservation Investment Consultant, Interview, 2018)
Computational cost can be high	<ul style="list-style-type: none"> • Computationally expensive and energy intensive • Possible slow transaction times • Limited blockchain storage capacity for IoT-devices 	<ul style="list-style-type: none"> • Different blockchain types can be less energy intensive • Private blockchains for selective transaction and information storage 	(AEternity; Cornell University; EOSIO; AffiliateCoin; Asch; GoChain; Watanabe et al., 2016; Ahmad, 2017; Imbault et al., 2017)
Errors are hard to amend	<ul style="list-style-type: none"> • –onyms and semantic gaps where natural language can mean multiple things can cause errors • Long code creates a higher chance of error • Can impact such things as asset ownership • Can't reverse errors 	<ul style="list-style-type: none"> • Create a new chain where the error does not exist • Legal agreements prior to smart contract deployment which states who is at fault and what will happen if an error occurs • Test code prior to deployment 	(University of Electroci Science and Technology of China; Luu et al., 2016; Mik, 2017; Magazzeni et al., 2017; Idelberger et al., 2016; Frantz and Nowostawski, 2016; Li et al., 2017; Smart Contract Developer, Interview, 2018)
Fiat cannot be transferred	<ul style="list-style-type: none"> • Can't transfer fiat (dollars, euros, pounds etc). • Oracle service can transfer fiat, but requires access to sensitive banking data 	<ul style="list-style-type: none"> • Fiat backed tokens or those that maintain a 1 to 1 exchange rate 	(Genesis Vision; Imperial College London; Nexo and Credissimo; OmiseGo; Photochain; Ripio; Stratis; Terra Virtua; Tether; VeChain; Xchange App; FlightDelay; BitBay; JOYSO; OxProject; Picolo Research; Porini Foundation; Egelund-Müller et al., 2017; Conservation Investment Consultant, Interview, 2018)

- Cryptocurrencies are too niche for small NGOs and other conservation companies
- Cryptocurrencies are volatile
- Smart contract execution on many blockchain networks requires a cryptocurrency fee
- Platforms that enable fiat payment which is automatically converted to tokens for smart contract transfer
- Oracle use to monitor the token-fiat conversion rate to maintain a constant, accurate rate

Full transparency may be unwanted

- Information is shared to everyone in the network
- Verifying identities entails sharing personal details
- Some information, such as exact species locations, should only be shared with some nodes to avoid such things as poaching, animal rights protests or unwanted tourism
- Private keys and encryption can restrict access to data
- Private and permissioned blockchains restrict access to certain individuals
- Zero Knowledge Proofs prove fulfillment of a condition without revealing the exact data such as proving an individual is over 18 without revealing the exact age
- Some blockchains specialize in restricted access
- Software guard extensions can restrict access to code so nodes can only view smart contract outputs, such as TRUE/FALSE or a numerical conclusion, but not the actual code or the data that was shared to reach an output
- Require tokens to access network
- ID verification by sharing photos of IDs and using AI to confirm ID prior to gaining access to a network

(APhotochain; Storj; Intimate, Photochain; bioBIT Network; Nuls; Porini Foundation; Swarm; Intimate; Regen Network; Alharby and Moorsel, 2017; Egelund-Müller et al., 2017; EWB, Interview, 2018; Smart Contract Developer, Interview, 2018)

		<ul style="list-style-type: none"> • User rating systems based on transaction history to ensure only those with good behaviour can participate and view a network 	
Large files cannot be stored	<ul style="list-style-type: none"> • Storage space is limited • Blockchain storage is computationally expensive 	<ul style="list-style-type: none"> • Encrypted file stored in decentral off-chain system and hash stored on-chain • Oracle service performs basic analytics to return TRUE/FALSE or numerical value instead of storing file 	(Porini Foundation; Engima; EY; Imperial College London; IPFSI Opus; Storjl Tron.Network; Wageningen University and TNO; Corda; WINGS; The Zenome Project; BVRIO; Regen Network; DeepBrain Chain; Faceter; iExec; Xu et al., 2016; Mik, 2017; Smart Contract Developer, Interview, 2018)
Legality of smart contracts is questioned	<ul style="list-style-type: none"> • Enable illegal activity • No way to confirm with full certainty that someone is of the legal age to enter into a contract • Manipulation possible • Interaction of different country laws • Laws do not inhibit smart contract execution 	<ul style="list-style-type: none"> • Legal agreement in place if an error occurs • Needs more research 	(Li et al., 2017; Giancaspro, 2017; Savelyev, 2017; Smart Contract Developer, Interview, 2018)
Outside data cannot be accessed directly	<ul style="list-style-type: none"> • Cannot access external data alone • No systems to check that data is correct prior to sharing • Connectivity to external data platforms with closed APIs are computationally expensive • Remote access to data must be enabled • Oracle service reduces trust and reintroduces single point failures 	<ul style="list-style-type: none"> • Oracle services enable connection to “outside world data” • Direct connectivity to data source can decrease falsified data • Decentralised oracle systems can eliminate single point failures 	(IBM; Regen Network; Waltonchain; Provenance; FlightDelay; AElf, Anz & Wells Fargo; OmiseGo; Alharby and Moorsel, 2017; Extrance, 2017; Cuccuru, 2017; Khan and Salah, 2018; Xu et al., 2016; Sergey and Hobor, 2017; Smart Contract Developer, Interview, 2018)
Smart contracts are inflexible	<ul style="list-style-type: none"> • Code cannot be changed once deployed • Outcomes are irreversible and unchangeable 	<ul style="list-style-type: none"> • “If, then, else” statements account for multiple outcome possibilities 	(International Business Machines Corporation; Zilliqa; Xu et al., 2016; Luu et al., 2016; Cuccuru, 2017; Levy, 2017; Sklaroff, 2017; Mik, 2017; Smart Contract Developer, Interview, 2018)

- Cannot be vague
- Must be inclusive of all possible future conditions
- May be more expensive to write than a traditional contract and can limit scalability
- Can also be stopped using “autokill” functions