# Unified Ecosystems & The Digital Transformation of Natural Resource Management: Applied Technologies

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**Abstract**

Environmental sciences promote the idea that earth's natural systems are architected around an all inclusive, complete feedback loop system. This ecosystem is connected in measurable ways, and plays a much larger role in the environment of the world as a whole. However, the management systems and the data collection conducted by our society is based on fractured, sharded, governmental agency data management methodologies, whose infrastructures do not allow for aggregated, enumerated outlines of the natural ecosystem. Administrative agencies collect vast amounts of data, and have been doing so for decades. But this data resides in un-relational, unconnected databases with little interaction between datasets. Because of this, policy decisions never take into account how the data relates in this unified system, and environmental management decisions become isolated and inefficient.

In this paper we research and suggest the use of new technological advances in data management architecture, distribution, intelligence and verification to correlate all environmental data under one system to produce positive benefits in policy enactment and enforcement. We suggest the specific use of a Data Store architecture, document/object oriented databases, distributed network databases, dynamic API, blockchain verification, neural network learning intelligence, and Smart Contract enforcement of environmental policy to resolve these underlying issues. By incorporating each of these elements into a unified inter-agency data system, we conceptualize a platform where information involving environmental resources flows freely, and administration of this interconnected ecosystem is properly applied though all-encompassing intelligent policy enactment.

**General Overview**

*Thesis Statement*

We can establish better methods of environmental resource management by aggregating data into an all-inclusive Data Store architecture, which incorporates a document/object distributed database to harvest data over a dynamic API, verify it with a blockchain, and mine the necessary policy making intelligence with neural networks, allowing Smart Contracts to correctly advise or administrate our natural ecosystems.

*Context/Framework*

Scientists have theorized the natural world ecosystem as an integrated dynamic system network. Environmental Management systems depend on making intelligent decisions based on all data possible in a networked system. But lack of verifiable information, un-relatable information, opposing priorities between departments or agencies, congressional oversight, and siloed data sets managed by these institutions create imbalances in our decision-making processes. Current systems do not support the integrated model of a networked natural ecosystem because of their insulated departmental foundations and political policy processes. Current environmental management policies inherit political deficiencies because of these inter-agency frameworks. Environmental action plans do not take into account all inputs and outputs of ecosystem's natural resources, and do not support the administration of a wholly connected natural environment. New technologies and designs should be applied to alleviate these problems.

*Justification/Argument*

New innovative technologies could lead to better implementation of a more intelligent public environmental policy action plan and it's subsequent administration. Old theories and new

methodologies could make the system of environmental management more suitable to actual needs. Current platforms hold vast amounts of information sets that are underused, and more data related to the natural world is being exponentially collected daily. The insulated, sharded nature of our administrative agencies and infrastructures is inefficient. A unified system to control and access this data is imperative for the proper management of natural resources. Systems that validate data or transactions between management agencies would create transparency and trust in the parties providing data. The ability to mine unstructured data across systems holds significant value and potential for new insights. Public policy enactment and enforcement should be based on event driven contractual processes that work well within the existing structures of our administrative bodies. All of these mechanisms and methodologies would be better applicable to the administration and concept of a unified natural world ecosystem.

*Literature Review*

In this paper we will review a variety of research materials ranging from peer reviewed journal articles about new technologies, currently implemented governmental digital platforms, and established frameworks used for environmental management. We also include reviews of current methodologies with potential guidelines and examples for integrating these technologies. We also try to define the accepted theory of our natural world as a connected, distributed ecosystem, and why this concept is important to its management. We do not go into great detail over the political process in which management policies are approved. In our research, we highlight technology techniques that should be applied for administrative benefit, and do not include the call for existing administrative structures to somehow be re-engineered. We focus

more on the creation of inter-agency backend platforms and data systems that would lead us closer to unified management, and intelligent planning for our natural resources.

**Background**

*Unified Ecosystem Management*

Although our world is structured on pre-existing governmental frameworks that manage and allocate natural resources in a segmented manner, it is important to note that scientists believe the world eco-system is an all inclusive environment where all variables must interact together in the same simulation. We may manage our natural world in a disjointed manner, but the world's ecosystem, as a whole, works as one. This connective entity can be seen in the effect of ocean temperatures in the creation of strong inland storms, to sand of the Sahara desert causing snow precipitation in the Himalayas.[1] The world's environmental system works together in one continuous giant feedback loop, where every input and output influences the entire model in real time.

*Theory of a Dynamic System*

Arthur Tansley first examined this the concept of the natural world interconnectivity in the early 20th century. His studies introduced the meaning of ecosystem and ecology to the world.[2] His early concepts relied on the foundation that the natural world is a series of networks, and beneath the entanglement of these networks, were systems. This concept spawned the modern theory of ecology and the conceptualization of the natural world as a linked, vast interconnected network of circuits, all dependent on one another for inputs and outputs. Whether balanced or imbalanced, this system works as a singular unified system.[3] [4]

Years later in the late 1940s, Jay Wright Forrester, a US government technology researcher specializing in system dynamics, suggested the idea that the entire world was composed of networks that relied on a instrument called feedback.[5] Everything in the world from human creations to the natural world could be seen as coordination of systems managed and governed by networks of feedback loops.[6] In turn, this abstraction pushed academics to model and examine the natural world as a machine. By applying the early ideas of cybernetics, which aimed to look at the structure, constraints and possibilities of the world as a whole, scientists could better examine the nature of feedback in environmental inputs and outputs then model them, subsequently simulating the larger natural world ecosystem.[7]

By applying the theory of a complete world ecosystem, and the networked mechanisms of feedback loops in this system, scientists and ecologists intended to model this dynamic system. George Van Dyne from Colorado in the 1970s was one of the first to try to model an entire grassland ecosystem with a computer simulation.[8] Collecting all animal, earth and plant datasets available in a unit of land, and incorporating the scientific methodologies of that time period, he demonstrated what an all-inclusive natural environment would look like in a simulation using a computer program. Though his research at that time was archaic in terms of today's standards, his model could not find patterns or large correlations between variables to produce. But his research was one of the first attempts to piece together the large nature of the world ecosystem in a complete model.[9] [10]

Governing policy during these aforementioned years had an insignificant impact, with little understanding over this interconnectivity of the natural world. Jay Wright Forrester continued through the 80s to push the idea that everything in this world is connected. In his studies involving the limits to growth, he made an impact on the public community by showing

how to put all the small pieces of the world system together into one large network, and his conclusions suggested, there were definitive limits to that system. [11] From commerce and industrial output, to natural ecosystems and pollution, he intended to web together a framework of the world ecosystem.

*Modern Methodology*

Modern day analysis of the natural world continues to rely heavily on previous historical frameworks outlined in the early 20th century. Ideas of a whole ecosystem are prevalent, and the collection of more environmental data is paramount. But the current systems of management in place are based on old paradigms, with separated existing governing bodies and agencies creating contradictory missions and methods of management. [12] Today in the United States, watershed is measured by one governing body and agriculture water usage by another. [13] [14] Though both agencies produce vast amounts of environmental data, much of which is shared, the majority of correlated data between inter-agencies is produced with the help of third party auditors or scholastic institutions, and these systems remain disconnected.

The main Federal environmental policy institutions and agencies include: The Department of Agriculture, The Department of Commerce, Department of The Interior, and The Environmental Protection Agency, with an equal number of smaller agencies that also have some impact on environmental policy.[15] These institutions in most cases have their own data, with varying methods and platforms to manage environmental data collected for policy creation. Although there is guidance from the executive and legislative branches in regards to data creation, distribution and retention, these agencies widely get to collect and manage environmental data anyway they choose.[16]

These agencies are separated into functional groups. The Department of Agriculture, who oversees the Forest Service, Natural Resource Conservation Service, and the Farm Service Agency, collecting varying sets of data from forest fire prevention methods to the amount of pesticides applied to farmlands.[17] [18] [19] [20] Their mission is primarily bound to collect information relating to food and food production, but they also measure wild-land variables to protect natural resources, such grass grasslands and timber production.[21] The Natural Resource Conservation Service also works with private landowners to conserve natural resources. Information on all these varying subjects reside in multiple databases. Information about agriculture resides in the NASS databases, whereas Forest Service input is accessible through the Recreation Information Database.[22] [23]

The Department of Commerce was instituted to monitor and promote economic growth.[20] But strangely enough, The National Oceanic and Atmospheric association (NOAA) is also under their supervision, as well as the National Weather Service, and the National Marine Fisheries Service.[24] This agency works primarily on job creation and economic output statistics, but data in their collections includes rainfall and offshore fish densities.[25] Platforms under this agency, used to access types of varying environmental data, include: Soil DataMart, Cropland Data and the National Water and Climate Center Database. Each type of data collected by this department has it's own database and specialized access platform.[26] [27] [28]

Similar structures exist in The Department of The Interior where other subsets of national resources are managed along with those involving cultural heritage. Mineral, water and national parks are also controlled under this agency. [29] As seen in other departments, each management category subset of management has it's own set of platforms and data. One small branch of this department, The US Fish and Wildlife Service, has The Bird Conservation Node, The

Threatened and Endangered Species System, The Environmental Conservation System, and the National Fish Strain Registry under its authority. [30] [31] [32] [33] [34]

The US Geological Survey also under this department has numerous database platforms and datasets as well. Important metrics such as hydraulic information is collected along with topographic and geologic information. But a myriad of other datasets are available under this agency, aquatic biology, botany, ecology, planetary sciences volcanology and geography are all subsets of study and datasets collected by this agency. [35] Most have their own database and access platforms. The National Water System stores data in NWIS, Biodiversity information can be found in BISON, migrating bird information can be found in The North American Breed Bird Survey called the BBS, and Ocean Biogeographic information is housed in the OBIS database.[36] [37] [38] [39]

**Key Issues**

**Technology Management Issues**

- Define the concept of a unified natural world ecosystem
- Show influences of a unified approach on current environmental management
- Inspect the fractured digital frameworks of agencies managing natural resources
- Survey impacts over inefficient departmental environmental management systems
- Demonstrate of the requirement of new interconnected technology applications

**Technology Application Issue**

- Highlight methodologies to unify & consolidate all data sets into one platform
- Research how to implement a system to handle all unstructured datasets
- Review of methods to scale and distribute massive datasets
- Examine possible interfaces to better consolidate, amalgamate and manipulate data

- Suggest new technologies to authenticate and manage data transactions
- Explore concepts for extracting intelligent correlations from data
- Investigate technology applications to advise or administer environmental policy

**Analysis**

*Current Models & Issues*

The idea of a wholly networked, natural world has been theorized for over a century. Thousands of studies over that time period have tested this interconnection and have tried to model the intricacies of such a dynamic system. In its current form, natural world management includes many different facets of governmental policy and governance in its execution. The myriad of systems used are designated and categorized into functional groups that apply policy at different levels of the management process.

If the theory of a wholly connected natural world is considered an important variable in the management of the environment, the question remains: How do the current structures, models and methodologies affect the management of these natural resources? In many ways, research suggests the siloed nature of our information and governmental frameworks has a negative impact on natural resource management. Independent audits of federal management systems point out that the current approach "represents a quintessential example of a 'problem of fit', where the authority of jurisdiction of the management institution is not coterminous with the problem."[40] With the myriad of agencies split between The department of Agriculture, Commerce, and Interior, institutions in control of the complex tasks of natural resource management are faced with increased challenges based on the multi-jurisdictional agency foundations.

This inefficiency can be seen in many different areas of natural resource administration where differing agency perspectives and methodologies create a low adaptive capacity to resources management as a whole. When taking a detailed look at the way our forests are managed for fire prevention, it has been noted, that the policies enacted by governing bodies, "no longer reflect the technical imperatives of environmental management."[41] Advisement of external governing bodies as well as the inclusion of public and congressional oversight has lead to inefficient enactment of policy based on scientific technical data. For instance, the National Forest Service in fire mitigation has experienced a situation where "Members of congress may be able to channel more fuels management to their own districts based on their electoral needs."[42]

This fragmented nature of our agency and departmental governing structures can be seen in all facets of natural resource allocation and protection. Even entities considered not to directly influence large-scale management of natural resources have run into these issues. The department of Veteran affairs concluded that, "Almost 40 years after regulations were issued detailing how US government agencies should conduct Environmental Impact Assessment, many federal agencies still have trouble doing EIAs in a timely, efficient effective manner. [43] Renovating a historical veterans hospital to modern standards meant relying on multiple agencies to conduct an impact assessment, and in many instances, "were treated as matters of concern only to the agency and its contractor." [44]

For those agencies directly in charge of natural resource management, it has become apparent that, "No single agency has the resources or geographical authority to manage transboundary resources, in a unilateral way."[45] For the most part, each insulated agency has experienced, "Inhibiting institutional factors" which include "lack of human resources, lack of information to make informed decisions and uncertainty about potential impacts."[46] Each

governmental department operates separate from one another and is subject to its own specific public input and congressional oversight.

Although much of this hindrance to natural resource management comes in the form of multi-scale and multi-jurisdictional conflict between agencies, primarily based in the political frameworks imposed at the time of their creation. The issues specifically relate to the design and collaboration of information data collection and connectivity. [47] The journal Nature explains the concerns of this conflict, highlighting that, "Each agency is responsible for coming up with its own procedures for guaranteeing data quality and handling."[48] While the priority of these institutions is to promote proper management of natural resources, it is difficult to conceptualize scientific thinking on these issues, "on the grounds that it relies on 'inaccurate' computer models."[49] With each agency acting upon its own accord collecting and disseminating their own version of environmental data, the whole unified system structure of the underlying natural world will never be taken into account. Or put in other terms, this structure of informational data governance encourages "a culture of working in silos."[50]

Securing an unlimited model of the natural world and it's resources is the only way to model a comprehensive ecosystem, considered by many institutions as unattainable. As each entity has a specific framework to follow, with sharded sets of informational data on the natural ecosystem, many find that "none of the assessments fully integrate all of the ecological principles and ecosystem vulnerabilities."[51] Data is separated by department, and management approaches are detached by agency specific guidelines and frameworks. This narrow model of data retention and intelligent decision making over the natural world means studies and management policies are "independent of, and external to ecosystems."[52] Our current methodologies have yet to put the pieces of the larger puzzle together in an all inclusive

congruent manner. What it still missing from our conceptualization of the full picture is "an integrated approach to data collection and management that considers the entire ecosystem, including humans." [53]

*System Innovation*

Many of the solutions provided by experts and academics imply that these governmental natural resource management institutions must go beyond the given structures set forth in their original designs to create a united, cross-operational collective system to manage the greater natural ecosystem. Many believe "decision makers can move beyond single-sector practices and promote the sustainable use and long term health" of these natural resources if they adopt a strategy of synergy and cohesiveness between these managing parties.[54] Though agencies may be separated by varying congressional oversight and budgetary constraints, working together to create policies that affect the wider ecosystem as a whole are necessary.

It is beneficial to mention that many, if not all, management institutions work in cooperation on projects and policies. The BLM functions directly with the outlines created by the National Forest service in regards to fire protection, the Agriculture Department directly incorporates data from the Commerce Department's NOAA research, and other interactions by the innumerous government agencies in charge of natural resources happens daily.[55] But the system and framework for an all inclusive management and decision making body, which includes processes and connective informational frameworks, still does not exist. What is truly needed to fully manage the national natural ecosystem is "management based on stakeholder collaboration; interagency cooperation; integration of scientific, social, and economic information; preservation of ecological process; and adaptive management."[56] In present day,

based on the fractured siloed nature of the systems established to manage natural resources, this integration does not function correctly.

To accomplish such integration, connective technologies and the data that drives such policy decisions must be made paramount. To compete against the varying agencies and departments that fracture the management of natural resources into small insulated arenas, technologies that " direct the collection, synthesis, and analysis of necessary information."[57] are needed. As we begin to take into account the complex connectivity of the natural ecosystem, academics in the field have promoted informational technology, and "exploring new approaches to multi-jurisdictional planning and management premised in knowledge, learning and collaboration.[58]

*Digital Transformation*

What seems to be an imperative issue faced by the environmental management agencies is the need to pull the science, data, collaboration, adaptiveness and decision making intelligence away from the structured institutions that command the policy process, towards a fluid flexible digital infrastructure. The institutions that have governed our natural world may be difficult to drastically change towards new ways of integrated thinking. New advances in old technological paradigms, coupled with advanced new innovations recognized in the field over the past decade, could help to alleviate the stifled policy process and management of our natural ecosystems.

As aforementioned, there is no lack of localized action in these separate agencies confronting the problems they are presented with. Hundreds of systems, platforms and databases currently exist to model research and predict the natural world ecosystem.[59] What lacks is the cohesive technologies to tie all the information available together, making such data sets more valuable to the intelligent decision making process. To understand the next step to take towards

integrated environmental management, we must take a look at the connective technologies that are transforming our private sector business and industry systems. If the goal is to create a framework for "Collaborative stewardship" with components for both management agencies and stakeholders included, applying these technologies to the public governance of our natural world is a logical step forward.[60]

We must acknowledge the scope and method of completion in such an undertaking must be made externally to the foundational structures of the governmental agencies. We by no means want to debate the manner in which these institutions are formed, funded, or regulated. What will become readily apparent in applying the suggested new technologies is that they can live and function external to these management institutions. New technology methods we highlight and examine can live in duplicity or externally from such institutional control. As such, the technology research we present that demonstrates these new mechanisms hold the greatest opportunity to change the way we manage entire natural ecosystems, without complete institutional remodeling.

*Applied Technologies*

*Data Store Architecture*

As data in these varying agencies resides in self administered systems, it is helpful to take a look at new data architecture structures that have the functionality to correlate all those data sets together within one system. Currently, governmental agencies incorporate old models of database management and schema, "where all the applications accessing the data live within the borders of the same organization."[61] This architecture is helpful to secure and manage information within an agency for it's own purposes, with systems managed by a central administrator and data being accessible only to known users, essentially preserving materials

from corruption. But what this sort of architecture does not promote is the "crucial point to obtain the maximum benefits from the explosive data growth, integrating information from different sources and also combining methodologies to analyze and process it."[62] With these siloed fractured informational systems based on agency, data will never be integrated to the fullest extent, and conceptualizing new solutions becomes impossible.

Without revamping the structures of these government administration agencies, a possible solution to aggregating data for maximum benefit might be found in an external Data Store architecture, "where data sharing is being extended from a single organization to an ecosystem of data owners and consumers."[63] This type of large-scale data sharing could be realized by establishing a governmental-wide Data Store which encapsulates varying data sets into one system. NOAA atmospheric information could live together with Geological Survey watershed data, and help to compute Department of Agriculture crop productivity estimates. This type of amalgamation could be spread across all pertinent administrative agencies. Each independent creator or owner of a particular data could still be in charge of its resources, but allow external parties to also access and manipulate they data as the deem fit.

This sort of external Data Store, which integrates all natural resource management agency information together, could allow "different users to share and reuse data while maintaining full control of their assets, both regarding the schema and data itself."[64] By incorporating other administrative technologies such as user and transaction identity-based mechanisms, which secure and protect data from being manipulated in the wrong way, a large-scale inter-agency Data Store could be possible. If the structure of the shared database incorporated a function to parcel components allowing agencies and departments to control data available to stakeholders, "this alternative should provide flexibility to independent users to build

applications based on shared data without any kind of intervention of the data owner. The same database stores objects from several owners, each of them controlling his part of the schema and his objects, and possibly enriching and consuming objects from other providers." [65] A Data Store with enhanced multi-entity functionality to alleviate the soiled datasets of natural resource management groups could add considerable value to our administrative system before policy enactment has begun.

*Document & Object Oriented Database*

A Data Store where all environmental information is stored and integrated is the first step towards a cohesive natural ecosystem management platform, but is dependent on what type of database is implemented. Traditional SQL table databases have a wide range of limitations when it involves storing massive amounts of unstructured data. Many of the systems established by these agencies, such as NASA's satellite imagery, or the Endangered Species Program's list of threatened species, incorporate many types of unstructured data, for example, layered images or network diagrams.[66] [67] When hypothesizing an all inclusive Data Store where natural resource agencies collaborate on shared data sets, having the ability to store and manipulate unstructured data is mandatory.

New advances in database schema design might alleviate the barriers that exist when applying the varying sets of data created by these administrative bodies. Document or object oriented database platforms, where "each object has an identity, represented by a unique object identifier, and can be shared (referenced) by other objects" would allow such a Data Store to consolidate many types of information under one platform.[68] Likewise, removing the table based design from the established agency databases would allow for more in depth mining of data correlations. Having the ability to relate data from The Bureau of Land Management to the

National Resource Conservation Service, the handling of that data "has to be more efficient, less expensive and more flexible" than traditional established models.[69] Object oriented databases, which can incorporate unstructured data like rich multimedia assets or imagery, "support efficient document handling involving storing, archiving and retrieving huge number of documents, including both contextual and non-contextual data."[70]

Designing an inter-agency Data Store to have the capability to process wide arrays of unstructured information, grants the ability for users to "share and reuse not only data, but also the methods that allows applications to manipulate it."[71] Whether it is enriched multimedia datasets, or applications that process and shape data for use, document/object oriented database schemas would be able to handle these irregular datasets on a large scale. The overall foundation of such an all-encompassing Data Store for natural resource management would require the inclusion of technologies that could handle such unstructured datasets.

*Distributed Networked Databases*

If we continue to expand the suggested approach of a single Data Store to aggregate and manage all inter-agency natural resource datasets, with the incorporation of new database schemas that can handle all types of unstructured data, we need to address the scalability of this system and its distribution. The vast amount of data created and collected over the years by these institutions is immense. Years of agriculture, forestry, atmospheric, planetary, hydraulic and geologic information can be found in the varying platforms these governing bodies have established. NASA's earth imagery alone surpasses much of the data all other agencies have developed.[72] When applying this Data Store and an unstructured object oriented schema database approach, we must investigate the platforms and systems that would be able to accommodate such mass data aggregation.

What is rather convenient about this architecture and these new database designs, is that they are formatted for the distribution of data over many nodes. “In a nutshell, a distributed system over the internet is an overlay network of storage and computing nodes, linked together in such a way to allow computational, storage and bandwidth resources to be shared.”[73] Distributed networked databases would allow for the massive large-scale storage of all inter-agency natural resource data, as well as the integration and distribution of that data. Furthermore, in addition to scaling for previously cataloged datasets, distributed databases “by design are intended for efficient management of large amount of unstructured data using horizontal scaling, thus removing obstacles stemming from the future growth of data.[74] Distributed network storage systems embrace unstructured data, configure to information types, and can scale indefinitely to fit new data streams.

These systems also take into account the separate  geographic locations of these agencies. The departments in charge of natural resources not only have federal offices that are not centrally localized, but also involve regional and local offices across the nation. By implementing a Data Store that relies on distributed storage systems, “ Files are not stored in their entirety at a specific location, rather they are broken up into many pieces, coded for redundancy, and dispersed to multiple locations.”[75] Allowing data to be replicated locally for latency, duplicated for redundancy, and distributed wholly to the entire network, would furnish this the theorized model of an inter-agency Data Store with the necessary tools and infrastructure to accommodate all datasets in relation to the management of the natural world ecosystem.

*Dynamic API & Websockets*

If we have the aforementioned technologies in place to create a unified Data Store for all natural resource regulatory bodies, the next operation that must be performed is inputting all data sources, from all agencies, into that platform. Fortunately most of the existing platforms holding information by these institutions have web interfaces or basic APIs to query and export existing data. Administrators understand that, "Interaction replaced information and instead of the traditional client/server mechanisms, a more convenient and standardized way of data is now needed."[76] APIs allow the data to be distributed, aggregated and computed externally from the providing agency. Because of this, accompanying agencies or the general public can easily access information related to watershed data without an administrator overseeing the process. Most of the natural ecosystem environmental data held by our government can be already accessed through a Websocket or API.

However, application interface languages and websocket technologies have seen substantial innovations in the past decade. The once "pull" only method, where data could only be queried and exported, has been transformed to a more dynamic interface approach. What has now become standard in these interface protocols is a two way stream of interaction between nodes. Now systems can either pull data for aggregation, or "push" data to another for aggregation. Many of these push pull interactions incorporate "real-time jobs that listen out for messages to arrive along a queue", and make the interactions between nodes a dynamic back and forth conversation happening in real time.[77] This is something many of the traditional systems established by natural resource administrative agencies do not coalesce into their existing methodologies. Yet, doing so would open up these data sets to a wide range of benefits, from creating new applicable data through the transaction of giving and receiving information, to gaining feedback as to what areas of information are important.

The nature of computer nodes talking to one another has changed along with these advances in dynamic APIs and websockets. In this environment, the structure and original design of these agencies and departments can be retained, but data can move freely back and forth between entities, liberating datasets and eliminating bottlenecks. Other attributes associated to dynamic APIs help orchestrate this process in a more efficient manner. Database platforms that are fully integrated through a modern API may incorporate application listeners that "listen to incoming data packets and can also answer.[78] In the case of applying APIs between natural resource management agencies, it might be beneficial to blend connector attributes into the transaction process, where "broadcasts can be filtered by any criteria, to eliminate duplicate or unneeded information from inter-agency distributions.[79] Or there might be an opportunity to be more timely with policy action by incorporating event model workflows, where "programming is characterized by triggering events."[80]

The incredible bulk of information these agencies hold, along with the myriad of varying types of data sets within these indexed data-sets, makes the task of pulling data to one large combined inter-agency Data Store seem impossible. But with the help of modern APIs to aggregate data in an intelligent ways, removing irrelevant data from these convoluted governmental structures, may be entirely feasible. Dynamic modern Websockets "provide the necessary flexibility that is required." in today's integrated digital ecosystems, and need to be implemented in these natural resource administrations and their successful coalition.[81]

*Blockchain - Verification & Transparency*

Eventually, if the systems are in place for a decentralized distributed database and the datasets from all relevant parties and agencies are dynamically flowing to and from this platform,

trust in the system, verification of datasets and transparency between inter-agency transactions must be realized. Currently, administrative bodies governing natural resources in the United States analyze and audit data and findings insulated from other parties, then present them to the public as stand alone reports.[82] This methodology negates the interconnected reality of the natural world ecosystem, siloing information into categorical initiatives and policy actions. What is needed is an interconnected system where all agencies involved in the management of natural resources have trust in the unification of all information.

In conjunction with the distributed network of data across all departments and agencies, what is needed is a public ledger of agreement on a Blockchain, which is a theory developed in the last decade, and fits this model perfectly. The foundation of a blockchain is built on the premise that many inputs share a common public register, and each member of the network completes verification of that register. The basic blockchain structure, "allows a digital ledger of transactions to be created and shared between distributed ledgers on a network. The ledger is not owned or controlled by one central authority or company, and can be viewed by all users on the network."[83] The idea, originally developed for monetary exchanges and the removal of governing bodies managing those transactions, is now being applied to all types of utilizations.[84] Banking was only one facet of use for blockchain. Academics suggest high potential applications of blockchain in land registration, digital identity, food security, climate change, urbanization and people's rights.[85] Natural ecosystem management fits the types of applications outlined in the recommendations. With many stakeholders being able to interact and verify information on a shared public registry, incorporating blockchain into the dissemination of environmental information could be the best way to build trust between agencies in a unified system.

The institutions governing our natural ecosystems are for the public good. Transparency and trust are paramount in promoting good policy creation for the environment and for the general public. Blockchain secures and verifies inputs in the aggregation and distribution of information over such an interagency platform in an unbreakable format. "Transactions are secure, trusted, auditable, and immutable."[86] In this environment, data shared between The Department of Agriculture, Commerce and Interior could live harmoniously in one system, specific data could be managed by pertinent parties, and the assessment of all information would be shared between all agencies.

In regards to oversight and auditing of this unified system "the requirement for socially constructed institutional third-party providers of trust is significantly reduced; they become disintermediated." [87] Blockchain inputs are verified by every node in the network and by every transaction processed. With the application of such a system governing the shared Data Store, trust, verification and transparency is coded directly into the distributive nature of the system and the information input itself. Applying blockchain to the data and transactions administration of such a system would bring trust, verification and transparency to the unified system.

*Neural Networks & Machine Learning*

With all the components pieced together in this theorized system, the question remains; How do we make informed intelligent decisions for policy enactment? With the enormous nature of information and Data Stored, collected and correlated in such a system, what becomes apparent is the need to look beyond sharded datasets and to see connections between knowledge bases. Experts in each departmental agency already perform analysis and recommendation on the information they control. What is needed is a framework to further contemplate the data we have

and emphasize correlations and recommendations that we are not currently considering in policy creation.

The concept of neural networks and machine learning is not something new, and was a system of understanding during the time Jay Wright Forrester was researching feedback loops and cybernetics in the 1940s. But recent advances in computational processing and neural network methodologies has created a reemergence of these theories to find patterns and correlations in large unstructured datasets. Deep data mining, using machine learning techniques, "is defined as a method of studying hidden valuable understanding within the resource by reading massive portions of information units."[88] It goes beyond the traditional rules set forth in human managed statistical analysis and highlights clusters of information that may go unseen.

With wide varying inputs included in this model, such as historical weather info, crop output data, or bird migrations statistics, it takes tremendous computational power to connect the dots between these information sets. Data mining using machine learning techniques, leverages the computational power of object oriented distributed data platforms and performs "unstructured" learning processes to focus and consolidate clusters of data across many informational units. Unstructured learning "concentrates on detection of patterns, in huge chunks of data."[89] It targets connections in information that may not have been seen by the human eye. Incorporating such analysis in the proposed system would allow for deeper reasoning as to how natural world ecosystem works in a unified environment and how current policies may be better tailored to account for these unforeseen ecosystem interactions.

*Smart Contract Applications*

Based on the extrapolated unified data system set forth in this analysis, which is verified by the entire distributed network, and includes deeper intelligence into the correlations of unstructured data, the next step in this system is to apply it to the agency driven decision making process for inclusion in the creation of better policies for environmental action. As we have communicated earlier in this paper, it is not our intent to change the structure and frameworks established by governing bodies to manage natural resources. We have highlighted the negative impacts such systems create for proper policy creation, but understand the surmountable effort needed to change such systems on a legislative level. That is why the objective of this investigation is about changing the technology information systems involved in the process, which have a higher chance for successfully innovating these agencies, rather then trying to change the structure of the administrative agencies themselves.

Getting unified data and intelligence across an inter-agency landscape to apply to policy creation, is the real crux of making this sort of model a success. Consequently, to properly employ the outlined system we must incorporate a system that manages and directs the creation of environmental policies. Thankfully, a fundamental tool used in other distributed networks and blockchain implementations is a mechanism called the Smart Contract, widely used in most of these applications. In essence, "Smart Contracts are computer protocols that facilitate, verify and enforce the performance of contracts: self executing code."[90] If we have completed the tasks of automating information aggregation, dissemination, and computation of relevant data, we must also apply that fundamental to the enforcement of the management policy.

In essence, natural resource policies spanning these varies agencies are contracts of regulated operations to be taken on environmental resource issues. A policy on wildlife protection might contractually influence the EPA, National Forest Service, the Department of

Energy, and other agencies. There might exist outlined rules or manners of negotiation within these actions, all of which are found in legal contracts. Usually, these actions are determined by congressional oversight, or third party auditors and private monitors, performed in a linear step by step format. But in actuality, most of these actions can now be somewhat automated. Smart Contracts "are the automation of the performance of contracts which only execute when pre-specified conditions are met. Thus removing the need for third party resolution."[91]

If the proposed system were to incorporate Smart Contracts somewhere in the process flow of information from one agency to another, and then onto policy creation and enactment, we may be able to remove some of the bottlenecks and shortcomings outlined by fractured parties in this process. That is not to say there are some drawbacks, as a Smart Contract "performs no matter what", and we may not want to implement automation in all fields of management.[92] But in many cases, policy, regulation of natural resources and sustaining the natural environmental ecosystem could have Smart Contract methodologies applied. Geological survey watershed data could trigger arable crop water limitations in the USDA and then trigger the enactment of water conservation rules in urban areas, completely removed from congressional oversight. Or at some point, if this is too much power given to a computer program, Smart Contracts could be used before human policy creation to guide those involved to properly formalize a quality policy. With either outcome, coupling contractual enforcement technologies in the process of natural resource management should streamline the overall policy process and make it more efficient.

**Conclusion**

The administration of our natural resources and the environmental world ecosystem must work in a unified manner to address the future sustainability of these networks. With the

potential predicted changes in these ecosystems due to climate change and human influence, a cooperative plan for management of these systems must be established. We must embrace the idea, which been built upon for over a century, that environmental ecosystems function as vast interconnected networks of circuits, all dependent on one another for their survival. By doing so, we will be able to better simulate a real model of the natural world in conjunction with creating actionable management plans for its preservation.

The current status of our fractured systems spanning multiple agencies and departments creates a situation where the application of management policy falls short. For instance, The Department of Commerce sets it's own guidelines for marine fishing, while the Department of Interior sets its own guidelines protecting fish habitats. These bureaus of administration, shaped by humanity's existing frameworks and ridged institutions of control, will never generate the necessary interconnection to manage a unified world ecosystem. Inter-agency conflict, cooperation and adaptability in this environment greatly reduce the affective implementation of policy enactment by governing bodies. A unified ecosystem model will not be properly managed without better collaboration between administrative institutions.

Instead of completely redesigning the frameworks set forth by the US government to manage natural resources, a feasible solution would be to remove decision-making information from the confines of these agencies and aggregate it into a comprehensive interconnected platform, where administrative institutions can cooperate in the distribution, correlation, and governance of data over the entire natural ecosystem. Data can live separate from physical institutions. NASA solar data is not proprietary and should co-exist with NOAA tropical storm information.  Datasets do not need to be bound by the institutional frameworks of a larger organization. In the context of natural resource management, the highlighted inefficiencies we

mentioned in policy enactment relate directly to this unification of information across all organizations. The BLM only marginally consults with the Forest Service on timber production and vice versa. A logical resolution to this issue would be to establish an inter-agency platform that encompasses all stakeholders within the management process.

To achieve such an integrated system, we suggest the implementation of a Data Sore architecture to sync all data between institutions. By removing the constraints put on individual departments or bureaus, data in this external architecture would be allowed to move freely and be used by all management institutions. The proposed Data Store should be implemented outside of one agency's control, and be able to interact with all other departmental datasets. In this scenario, The National Parks Service could interact with data from The Department of Agriculture's Forest Service, or The Environmental Protection Agency guidelines could be used to guide The Farm Service Agency on proper pesticide use, without the need for third party action. A Data Store architecture takes all of these fractured, sharded datasets, and makes them useful to a wider field of applications.

Additionally, implementing that Data Store architecture on a document/object oriented database would allow the information housed to be more flexible in its use. Being able to correlate all data by key indicator metadata instead of say file type, would allow us to incorporate a wide variety of data like multimedia or images along with contextually oriented documentation. This ability to aggregate and manage unstructured data in one system would grant the mixture of U.S Fish and Wildlife data with USGS soil data or surface mining estimates to reside in one place.  Endorsing a system where all types of unstructured data and co-mingle would allow these agencies to make better correlations between department guidelines and policy initiatives.

Furthermore the proposed Data Store should be allocated over a distributive networked database. There is no reason that data should be hoarded in insulated agency infrastructures. Redundancy can be built right into these distributed databases spanning geographic locations. With Data Stored and shared between all administrative bodies in this network, there is no influence of organizational structure preventing data from being shared. The scalability of such a system is also no longer relevant; capacity is shared with everyone in the network. Why should NOAAs weather data be made to live on only their databases when that information is consumed by almost all other agencies? A more efficient model would be to share that data over a distributed networked storage architecture that alleviates individual departmental constraints.

Accompanying this distributed model, data housed should be channeled back and forth from each agency over a dynamic API. Information about bird or fish migrations does not have to be dumped into this system in a raw illegible format. We can manipulate the incoming data to fit certain criteria for better use, as well as structure out going data for better feedback. As intelligence is learned about the way different sets of unstructured data interact, it's important that a two way communication from agency databases to the unified Data Store is realized. Important correlations such as real time fish populations could be fed back into agency models for re-analysis incorporating the dynamic APIs in the process. Creating and adaptive environment where information can be passed easily through the system, for any use, is possible when modern dynamic APIs and web sockets are applied.

Likewise, verification of datasets might be the most important aspect of the entire integrated model. Current methodologies do not build trust between bureaus. The EPA might say one thing about watershed qualities and the USGS might say another. By blending these systems with a blockchain, verification and transparency of data between stakeholders becomes

effortless. This authentication can also be applied to transactions between institutions. Atmospheric data could validate the decision making process of other agriculture administrative bodies, fire prevention expenditures could be substantiated by resource conservation services. Blockhain application could lead to an inter-agency environment where trust in the data becomes natural, while distributing control of that data to all parties involved.

These systems combined lead to a database of information that is unified. From this point we can then incorporate neural network machine learning to aid in the correlation of data and the intelligent extrapolation of information sets that could potentially highlight undiscovered connections. Relationships between wildlife migrations in relation to arable farmland allocations could be better explained. Hidden correlations between carbon monoxide estimates and global temperatures could be realized. What cannot be found in our current methodologies might be conceived when machines look for patterns and clusters in unsupervised data analysis. This heightened intelligence over natural ecosystem information would allow us to make better decision on how to manage it.

The final application of Smart Contracts in the process of managing our natural resources would assure all stakeholders that policy enactment and enforcement goes as planned. Whether this happens before public input and congressional oversight or after, allowing Smart Contract applications to control or advice natural resource preservation would guarantee data is enacted upon, and policy does what it is supposed to do. In many ways we should envision Smart Contracts working automatically on an event driven basis, controlling the intricacies of environmental policies and inter-agency transactions. But if it were too early to put a computer in control of our natural resources, it would be beneficial to allow Smart Contracts to be a guide for traditional policy creation. If natural ecosystems can work as a vast interconnect network

dependent on all other entities in the system, so can policy enactment. Smart Contracts allow us to take the human political factors out of the process, and focus on the relationships between data and action within the system.

The entire proposed system as a whole would help to take the fractured nature of our natural resource management today and digitally transform it to be a more efficient system for the future. If our natural ecosystems work as a unified entity, so should the policies and platforms that manage those resources. We can overcome the disassociated natures of the administrations that govern our natural world by focusing in on the digital platforms in the decision making process and integrating them together for higher efficiency. By creating unified integrated system of management for our natural ecosystems, we might actually be able to preserve them for future generations.

**Recommendations**

· Embrace the unified model of natural ecosystems & tailor management policies to adhere to this unification.

· Overcome the fractured inconsistent methodologies of our natural resource administration by focusing on the unifications of digital systems.

· Employ the design of a Data Store architecture for an all-encompassing management approach.

· Implement a document/object-oriented database to aggregate all unstructured datasets across agencies.

· Allocate a distributed networked database to distribute, house and scale to the massive data amounts required.

- Incorporate a dynamic API between all agencies to enhance the fluidity of information through the system.
- Introduce a blockchain system to verify and authenticate data, bringing trust to the network.
- Apply neural network machine learning to the decision-making process of policy creation to find new undiscovered correlations.
- Enact Smart Contracts to administer policy and advise agencies on proper natural resource governance.

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