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PRELIMINARY SURVEY OF THE INFORMATION PRESERVATION NEEDS

OF THE MARINE CONSERVATION COMMUNITY

A THESIS APPROVED FOR THE
SCHOOL OF LIBRARY AND INFORMATION STUDIES

BY A COMMITTEE CONSISTING OF

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Abstract

Observations of environmental degradation, ecosystem change, fisheries collapses, and biodiversity loss have raised concerns over our ability to preserve marine communities. Knowledge plays a key role in any attempt to preserve these ecosystems. However, the basic natural history knowledge necessary to understand these systems has also degraded as the discipline of ecology has evolved in response to technological pressure and changing funding priorities within science. To make matters worse significant species losses occurred before many ecosystems were monitored making it difficult to determine the nature of undisturbed systems. This thesis analyzes the data currently being produced by the marine ecologists and conservationists in order to describe to librarians and information scientists what efforts can be taken to preserve data critical for ongoing conservation efforts. Description of data generated for the purposes of aquatic ecology was obtained through a domain analysis of the journal Aquatic Conservation: Marine and Freshwater Ecosystems. Three years of data generation was recorded for all full-length research articles published between 2016-2018. The data is heterogeneous; however, important trends were uncovered. There is a large amount of geographic data being produced within the context of determining biodiversity. Physical sampling of the environment means that adequate data preservation requires museum resources play a part in preserving specimens. Accessibility of data will determine its utility to ongoing studies, and online resources can easily facilitate needed accessibility.

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Preliminary Survey of the Information Preservation Needs of the Marine Conservation Community

Chapter One

Introduction

Marine ecology presents a complex range of data and narrative information to the library and information specialist. Preserving the necessary knowledge to sustain the practice of marine ecology cannot be done effectively without an understanding of the range of knowledge products necessary to undergird the discipline. It is the product of a community and mere preservation of the various tangible documents and the array of technological recordings of nature do not convey all the meaning to be found within the scientific practice of ecology. The core of ecological knowledge, as represented by the evolving practice of natural history, has fallen from favor as an academic pursuit (Barrows et al., 2016; Bradley et al., 2014; Dayton, 2003). Ecologists have raised the alarm that the craft of natural history is not being transmitted adequately to the next generation (Bradley et al., 2014; King & Achiam, 2017). Various academic disciplines rise and fall in popularity as cultural pressure both within and outside of academia shape the kind of research that is funded. Natural history has been on the losing end of university politics for the past two to three decades (Bradley et al., 2014; Gropp, 2020). As a result, while threats to biodiversity continually increase (Hogue & Breon, 2022), our ability to track these changes is declining as new natural history collection efforts are increasingly ignored (Rohwer et al., 2022). That's long enough to break the chain of academic apprenticeship as represented by graduate education, since most of the professors that built their careers performing classic ecological experiments and making crucial observations have already retired (Barrows et al., 2016). This places the library and information specialist who wishes to preserve ecological knowledge into the position that requires an awareness of the culture of ecology as well as its content. There is an element of craft to the practice of science that is only partially articulated in the literature (Polanyi, 1974). It is not entirely possible to preserve this aspect of scientific knowledge without maintaining a vital community of participants, so something will be lost no matter how diligent the efforts of the library community are to preserve the knowledge of ecology. But lack of awareness of this problem means that more will be lost than needs be (Dayton, 2003).

This is not just an academic problem. Marine ecology represents an essential knowledge to the effective practice of marine conservation. The oceans are in a state of ecological crisis. Crucial coastal habitat has been lost. Many of the most exploited fisheries are facing collapse or have already crashed (Jackson et al., 2011, Pauly & Zeller, 2016). Oceanic acidification due to rising carbon dioxide levels threatens ocean life (Sahoo & Pandey, 2020). Coral reefs in tropical waters have faced increasing episodes of bleaching as ocean temperatures rise (Bertness, 2001). Toxins and sedimentation are prevalent in coastal runoff (Bertness, 2001). And all of this is exacerbated by the complex interconnection of the processes in marine ecosystems. It's impossible to affect a part of the system without risking unforeseen consequences to the whole.

The problems facing the marine conservation community seem nearly insurmountable. The loss of knowledge of the specialists that could contribute the most to providing the necessary stratagems to address these problems is not one that the conservation community can afford. If the oceans are going to be saved, our knowledge of the oceans needs to be saved as well. This thesis will examine the question of what means the library community can take to preserve the marine ecological knowledge necessary to provide the marine conservation community with the tools to address the current crisis. Part of this task involves examining the range of information products produced by the marine ecology community. While this task is not sufficient in itself to preserve the rich texture of community knowledge, it is a foundational step for assessing where library resources should be concentrated at this stage to ensure that the knowledge currently being produced by the ecology community will be preserved for the next generation. Collaboration needs to be fostered across a range of institutions as each institution holds part of the story necessary to most effectively preserve biodiversity (Poo et al., 2022).

Marine Ecology

What does current ecological practice look like? How is ecological practice applied to understanding problems faced in preserving the marine environment? Marine conservation is evolving as a discipline; ecologists have realized that a large variety of information resources from several disciplines are necessary to provide the information needs to describe the nature of ecological degradation and mitigate its results. In 1995 Daniel Pauly introduced the concept of shifting baselines to the scientific community, to show that marine communities had already degraded before scientific records had been produced to document the change. Essentially, Pauly alerted marine ecologists that the archival record within the scientific community was not adequate on its own to describe ecological change. The concept has inspired a new subdiscipline of marine conservation known as historical ecology. Ecologists have resorted to searching for a variety of archival records that predate the scientific record.

Natural history data is complex. The preservation of natural history knowledge is not simple. This chapter will provide a description of some of the complexities inherent in natural history knowledge. One concept within natural history that shapes our understanding of conservation is disturbance (Balke et al., 2015). Disturbance can be a natural phenomenon, but it also can be caused by human activities. Not all aspects of natural history practice are directly preserved within the literature that is published within the scientific record. A discussion of the limitations of what can and cannot be preserved by information specialists even if adequate human resources are dedicated to preserving the information relevant to conservation for the next generation is provided at the close of the thesis.

Shifting Baseline Syndrome

Daniel Pauly is one of the leading fisheries biologists in the world. His observations have helped shape the way conservationists interpret fishery records. In his 1995 paper Pauly introduced the concept he titled "shifting baseline syndrome," now frequently referred to as shifting baselines. In this one-page paper Pauly revolutionized the understanding of how fisheries needed to be studied to take into account historical changes in fish populations. He stated that when new scientists entered the profession, they assumed that the populations of fish and other marine organisms they observed at the beginning of their professional careers were representative of normal populations. In reality, fish populations had been in a state of decline for decades and in some cases for centuries. Over the course of a career, scientists had observed this change. By the end of their careers, they understood that the fishery populations they observed in later years were depleted and the communities had changed. But as they retired, this knowledge was not adequately passed on to the next generation. So new scientists entering the field assumed that the fisheries populations that they observed at the beginnings of their careers, represented normal populations.

The implication of Pauly's (1995) paper was that fisheries biologists needed some way to account for this change, even though it had not been adequately recorded by the scientific community. A natural solution to addressing this problem was to look for evidence outside of the scientific record that documented this change. This meant that fisheries biologists and marine ecologists needed to examine records from a variety of sources outside traditional scientific papers. In a landmark paper that has been frequently cited by marine ecologists and conservationists, Jackson and colleagues (2001) built on Pauly's work, further articulating the problem, and attempting to identify the means that were at the disposal of the scientific community to fill in missing knowledge. Jeremy Jackson is a coral reef ecologist, paleobiologist, and conservationist responsible for promoting the emerging subdiscipline of historical marine ecology as a means of creating a more accurate picture of the decline of marine ecosystems under the response to millennia of fishing pressure. Because Jackson and colleagues (2001) have done so much to shape the discipline, the paper will be considered in an extended review at this point in the thesis.

Written from a paleontological perspective, Jackson and colleagues' (2001) paper takes a wider historical perspective drawing on evidence from paleontology, archeology, and the historical record. The paper takes a long view of anthropogenic change within the marine environment identifying it as something that has been occurring since early human tribes organized into fishing communities. The paper warns that the marine coastal environment is both so fragile and complex and that even seemingly minor human intervention, such as the fishing activities of small pre-literate communities, can do lasting damage to the ecosystem. The most lasting damage has occurred in the last few centuries as a byproduct of European exploration and industrialization. Organized local field studies that have the capacity to scientifically document environmental change have only been a regular practice since the 1950s, meaning that the last several centuries of ecosystem disturbance initiated by European exploration, colonization, and industrialization has largely gone unrecorded by the scientific community.

Examining key coastal habitats, Jackson and colleagues (2001) document the impact of overfishing on fish and marine invertebrates, showing that ecological degradation spills over from targeted species into ecological interactions within the whole marine community. The paper states that studies from kelp forests show that trophic disturbances caused by fishing can lead to unbalanced communities and habitat loss. Complex interactions occur between predators, prey, and plant species. When a portion of this community is removed by fishing, pathological interactions can occur between species as the communities attempt to respond to the change. Coral reefs have also seen pathological interactions between species triggered by the pressures of overfishing. Habitat loss can be triggered by various anthropogenic disturbances such as pollution, sedimentation, and turbidity; however, trophic interactions in undisturbed communities help ensure ecosystem resilience. Trophic interactions occur between the various species found in the marine food web. Marine communities where fishing does not occur are sustained by the balance of interactions by all the organisms within those communities. Mortality of seagrass has been observed in seagrass beds due to a combination of physical and fisheries disturbances. A dismal list of the impacts of overfishing, physical disturbance, pollution, hypoxia and anoxia, sedimentation, and eutrophication accompany the histories of the range of habitats associated with the coastal environment such as estuaries and benthic communities. Overfishing can impact the carbon cycle, lead to toxic algal blooms, result in fish kills due to low oxygen as part of this complicated system of response to anthropogenic disturbance.

Jackson and colleagues (2001) warn, “shifting baseline syndrome is thus even more insidious and ecologically widespread than is commonly realized” (p. 636). Jackson and colleagues argue that marine ecosystems cannot be effectively restored without taking into account the deep historical roots of ecosystem deterioration. The article makes an optimistic statement regarding the potential to restore marine ecosystems by pointing out that comparatively fewer large animals are currently extinct in marine environments than in terrestrial ecosystems. The authors hope that restoration is still achievable in the marine environment, if people choose to act on more accurate knowledge of the extent of ecological disturbance associated with depressed populations of top predators.

After 2001 Jackson continued working in the same vein, attempting to articulate a new subdiscipline at the nexus of marine ecology, conservation, history, fisheries biology, and environmental history. He called this new subdiscipline "historical ecology", but its unique marine ecology and fisheries content can be better expressed as "historical marine ecology". In 2003 Jackson presided over a conference entitled *Marine Biodiversity: The Known, Unknown, and Unknowable* attended by leading experts in the field. A book based on that conference entitled *Shifting Baselines* (2011) drew on the expertise of some of the most prominent attendees. This book can be considered the first description of historical marine ecology as a coherent discipline. The book includes several essays where authors draw on historical data as a demonstration of work within this new discipline and can serve as a model for future work. Information contained within these essays demonstrates the use of archival sources.

In the introduction of the book Jackson and colleagues (2011) state what they perceive to be the purpose of the book,

> This book is a first joint attempt by scientists and historians to explore the significance of the shifting baselines paradigm. What does it mean for the future of fisheries and the ways in which we perceive our even more unnatural oceans? . . . It shows how new

> perspectives on the past can alter our understanding of oceans today and change the future for the better (p. 3).

Shifting baselines is a concept that requires a new approach to studying nature. It points out the inadequacy of scientific knowledge. The book continues,

> Shifting baselines is a truly fundamental and revolutionary idea, but the revolution has not yet happened because the challenges are enormous. . . . First, it is not enough to measure only what we see today because some of the most important changes happened before scientists began to measure them. . . . Second, shifting baselines challenges long-established goals for the management that were based on simplistic concepts such as maximum sustainable yield (MSY). . . . Third, shifting baselines makes us uncomfortable because it places all of us squarely within nature and holds us accountable for both past destruction and shaping the future (p. 3).

To respond to the concept of shifting baselines requires scientists to step outside of their comfort zone and engage data from heterogeneous sources outside of standard scientific practice. It means that scientists must grapple with the meaning of evidence that was not collected under the strict protocols of scientific observation and experimentation. It is data that most scientists are wary of. They question if it can be used in a meaningful way. As historical marine ecologists borrow the tools developed by historians, they must redefine how these tools are used. Their site of study has moved from the field into the archive. They need the skills of library scientists to make the best use of this new material.

For conservation to be effective, conservationists need information literacy skills in which few of them have been trained. Conservation is an interdisciplinary field. Knowledge is the currency that has to be spent, if the work of conservationists is to move beyond theoretical goals to a practice that can actually reshape the environment. Nature does not always behave the way people expect it to. Change is a part of nature. To effectively intervene in degraded ecosystems, not only is it necessary to understand what healthy systems look like, people must have some idea of the complexity of nature, resilience, and how ecosystems respond to change.

Disturbance

Disturbance, a key concept for understanding natural and unnatural changes that occur in nature, must be understood by ecologists and marine conservationists to work effectively. Understanding of the unnatural disturbance that threatens the survival of a healthy community is first built on recognizing natural forms of disturbance. Natural disturbance includes the physical and biological processes by which communities are disrupted. An example of physical disturbance in the marine environment can be a storm that dislodges algae and sessile marine invertebrates from the rocky substrate to which they are fixed. A common form of biological disturbance is herbivorous and carnivorous predation. There are also unnatural forms of disturbance; these frequently come in the form of human activities that alter a habitat. There are differences between the way natural and unnatural disturbances disrupt a community. Biological communities are adapted to respond to natural disturbance in a resilient way, but they are less resilient to unnatural disturbances.

Work that established understanding of natural disturbance as it related to competition was described by Paul Dayton (1971) in a paper that summarized his dissertation. Dayton studied under the well-known ecologist Bob Paine. Paine completed pioneering work that demonstrated that certain predators could exercise an important role in maintaining the diversity of the community. In a predator exclusion experiment (1966) Paine showed that removing the predatory seastar *Pisaster ochraceus* reduced the complexity of the rocky intertidal community he was studying. As the seastar fed, it removed patches of the organisms, consequently freeing space for the settlement of new organisms. The act of predation allowed for continuous recolonization of the site by a larger array of organisms. In 1969 Paine proposed the concept of a keystone species, an organism, whose presence or absence within a ecosystem determined aspects of the trophic structure of the system. Paine's work has a bearing on the work that Dayton performed in his dissertation, since it also addressed factors that help determine community structure.

Dayton (1971) conducted his dissertation research near the region of the Olympic Peninsula in Washington State. He selected eight field sites in the intertidal zone, the narrow strip of coastland that is sometimes inundated and sometimes exposed during the periods of high and low tide. He studied the comparative abundance of the sessile invertebrates as they responded to physical and biological disturbance in light of competitive dominance. The most frequent forms of physical disturbance he observed at his study sites were from wave activity, floating logs, and desiccation (drying during periods of intertidal exposure). He partially caged off patches of rock in the intertidal zone where he removed limpets, a conical form of mollusc that preys on marine invertebrates and algae. Dayton (1971) discussed his results in a paper that examined the space utilization of sessile invertebrates. This classic paper would later provide critical knowledge that is needed by the conservation community to further define how disturbance works.

Dayton (1971) found evidence of competitive dominance as species of barnacles and a mussel competed for the same space on the substrate. However, this community was exposed to continuous natural physical and biological disturbance, and the structure of the community responded to these factors as well as competition. Physical disturbance can frequently remove species from a settled site, starting the process of succession all over again. Predators also effectively remove species from these sites as well. As a result, communities change over time as they seek to continually establish new equilibriums. Disturbance is a fundamental concept in ecology. Natural disturbance is one of the primary factors that structures the range of ecological processes that influence the natural functioning of biological communities. Natural disturbance does much to dictate benign change in well-balanced ecosystems. Without understanding how natural disturbance works in marine ecosystems, it is difficult to recognize if observed changes are part of a functioning system or a warning sign of pathological shifts in community relations and growth. It is important within the context of conservation to be able to recognize the difference between natural disturbance and unnatural disturbance. It is impossible to disrupt a species within an ecosystem without the effects of that disruption impacting other species within the system. As a result, a targeted fishery will have consequences to the larger ecosystem.

Dayton's (1971) work on natural disturbance at the beginning of his career primed him to recognize that unnatural disturbance was the result of the activities of the fishing industry. Even though Dayton was a benthic ecologist (a benthic ecologist studies bottom habitat in aquatic systems) working outside fisheries management, he recognized the impact of the fishing industry on the marine community earlier than many fisheries biologists did. In order to understand marine conservation within the larger context of marine ecology, it is important to take the time to study the range of processes that shape the way biological communities function. Natural history is the study of the organisms and communities as they interact on a day-to-day basis. Natural systems do not always behave as people describe them as behaving in theory. It is important to take the time to observe nature in action. Without understanding natural history, marine conservation can be badly misapplied.

Dayton and colleagues (1995) show the impact of unnatural disturbance caused by commercial fishing and the various ways that fishing disrupted marine communities. It is essential for conservationists to recognize not only the direct impacts of fishing, but the indirect effects as well, or they cannot preserve the ecosystems they are managing. The first hazard associated with fishing technology discussed in the paper was the way that bycatch (bycatch includes the non-target organisms that fishermen extract from the aquatic environment as a consequence of attempting to catch target species) depleted many species of marine organisms that were not directly being targeted by the fishing industry. Fishing technology is very unselective in most cases and a wide variety of animals are vulnerable to being caught in nets, swept up in trawls, tangled on fishing lines, or caught in fishing pots. Many of the species that are unintentionally caught in fishing gear are discarded. However, most of the discarded bycatch suffer mortality as a result of being caught even if they are returned to the marine environment. This disrupts marine ecosystems in multiple ways. First, large numbers of organisms are killed by the fishing industry, and when their carcasses are returned to the ocean, they further disrupt the ecosystem by stimulating unnatural feeding patterns by predators.

Several groups of organisms are particularly vulnerable to bycatch. Marine mammals such as whales, porpoises, and seals frequently are inadvertently captured in nets. Turtles also are frequently killed or injured because of fishing gear. According to Dayton and colleagues (1995) turtles such as the Kemp's ridley sea turtle are threatened with extinction; with approximately only 1000 breeding adults the Kemp's ridley turtle is, "dangerously close to the threshold for minimum viable population size" (p. 209). In some areas large numbers of diving birds have been killed by gill nets. The use of trawls, dredges, and traps on benthic communities can have a particularly devastating impact. Trawling technology is used by being dragged across the sea floor, "The effects on the sea bottom include impacts such as scraping and plowing the bottom to substratum depths of 30 cm as well as causing resuspension of sediment and destruction of many bottom organisms" (p. 210). Benthic communities inhabit bottom sediments and substratum, meaning that trawling and dredging can disrupt the entire community. When trawling and dredging occur on a frequent basis, the system does not have time to recover.

Considering the impact of fishing activities on so many aspects of marine communities, thought must be given to the goals of managing the marine environment. Two objectives identified by Dayton and colleagues (1995) include the sustainable use of marine resources and the preservation of ecosystem integrity through its structure and function. However, there is frequently pressure on managing agencies to allow fishermen to maximize immediate profits, disregarding the long-term consequences. When ecosystems are managed without adequate knowledge of ecology, when uncertainties within the environment are not factored in, simplistic management policies that optimistically report large extractable resources frequently overlook how complex ecosystem functioning really is.

Productivity is naturally variable within the marine environment. Some years fish recruit in high numbers, while other years environmental factors can substantially reduce the surviving population. Dayton and colleagues (1995) indicate that exploitation of uncertain resources can lead to a mismatch in the economic investment in fishing equipment and the available resources that can be removed from the oceans leading to the collapse of fisheries. However, investment in fishing equipment can be quite expensive and fishermen can accrue heavy debts, meaning there is pressure to continue fishing beyond the means of the ecosystem to supply demand. As a result, intense political pressure from fishing communities is frequently brought to bear on resisting legislation that would help ensure that fisheries would be managed in a sustainable way.

Fisheries represents one kind of unnatural disturbance that is suffered by the marine environment. Other environmental insults include pollution, habitat fragmentation, and cascading ecological responses. Dayton and colleagues (1995) state, “Another important type of problem making environmental protection exceedingly difficult, if not impossible, under the present social and legal climate is that of cumulative, often low level disturbances” (p. 221). Often it can be difficult to untangle the impact of overfishing from other anthropogenic problems seen in the marine environment. These unnatural environmental stressors can work in tandem creating a greater crisis than the individual disturbances would cause on their own.

In a paper that has become a classic in fisheries biology, Pauly and colleagues (1998) demonstrated another form of disturbance caused by fisheries activities. Dayton and colleagues (1995) foreshadowed the issue that Pauly and colleagues more explicitly described. When fishing occurs at unsustainable rates, a phenomenon occurs that Pauly and colleagues have labeled fishing-down-the-food-web. The paper examined fisheries statistics from the UN Food and Agricultural Organization (FAO) from the years 1950 to 1994. This 45-year data set showed that there had been a shift in the nature of fisheries’ catch over time. As large piscivorous fish became over exploited the fishing industry had to shift its catch to larger numbers of smaller invertebrates and planktivorous fish. Fishing changes the structure of marine communities both through direct exploitation and bycatch. This causes disturbance both through direct removal of fisheries species and because the organisms in the now unbalanced system must survive in conditions for which they are no longer adapted.

To do their analysis Pauly and colleagues (1998) made use of Ecopath software. This software that Pauly was instrumental in developing helped him model ecological relationships of fisheries species. From the perspective of library science, the job of preserving knowledge necessary for understanding marine ecology and its relationship to conservation requires not only preserving the data but the tools and techniques necessary for interpreting it. Ecopath software is an example of this need. Over time software such as Ecopath is used by the community, however, tools like this evolve over time and can become obsolete. This presents two issues; the first one involves keeping track of changes in the way software works. The second issue is finding means of preserving obsolete software for future generations. If questions arise over the meaning of historical data sets, future scientists can reconstruct classic experiments if the software they used is saved. The job that library scientists have before them if they are to preserve the knowledge necessary for understanding current ecology practice and effective management of fisheries requires preservation not only of the products describing scientific work but the cultural knowledge that produced them and supporting material that makes the data transferable.

Current Knowledge Products for Marine Fisheries and Conservation

Daniel Pauly has been a leading innovative figure in the development of fisheries biology over the past five decades. He is responsible for the development of the most important online taxonomic product for the fishing industry. FishBase is much more than a record of the names of known fish species. It also records a range of ecological and biometric data for the species described. The scientific community has become increasingly aware of the need for online knowledge products that allow the community to disseminate and integrate the massive material associated with big data projects (Dahdouh et al., 2018; Jones et al., 2018; Leonelli, 2013; Parigi et al., 2017). In the case of Pauly's work, the community itself has led the development of these products. Another extremely important resource for the conservation community is the Biodiversity Heritage Library (BHL). This digital collection of historic and modern documents relating to biodiversity provides ready access to the largest collection of its kind. The BHL is a collaboration of scientific specialists and library professionals. While many other knowledge products for biologists and conservationists are currently available, these are the two leading resources of their kind currently available. To understand the needs of knowledge preservation within the community of ecologists and conservations, it is useful to examine what constitute two of the most useful knowledge products available to fisheries and conservation practitioners.

FishBase

It's impossible to manage fisheries without knowledge of the species being managed and the community of associated fish that are impacted by the fishing industry. According to Patrick and colleagues (2014) "In the late 1980s, FishBase began cataloging key life history parameters of the world's fish species" (p. 173). Grüss and colleagues (2019) indicate that over 34,000 species and subspecies of fish have been recorded on FishBase along with information of fish taxonomy, ecology, morphology, and metabolic information. In addition to FishBase, the fisheries community has come to recognize the need to expand fisheries knowledge products to include other classes of organisms. SeaLifeBase has been added to augment FishBase. As of 2018, 75,000 non-fish species have been included. FishBase is currently run by a consortium of institutions with affiliations to academia, government organizations, and museums, and SeaLifeBase has similar institutional affiliations.

To provide necessary conservation information, FishBase has also been adding vulnerability values to their website. Strona (2014) provides a comparison between the vulnerability values provided by FishBase and those provided by IUCN Red List of Threatened Species indicating which species are vulnerable to population loss or extinction. Strona found that the vulnerability estimates provided by FishBase depended on fish life history characteristics. The analysis was performed by comparing more than 2500 bony fish species. The IUCN values rely less on life history data but consider more vulnerability related to the geographic range of species distribution. Vulnerability values are derived indexes of data.

Information about at least 18 life history parameters can be found on FishBase and SeaLifeBase. Types of parameters include growth and morphometrics, longevity, fecundity, sex ratio, trophic level, and ecological factors. Patrick and colleagues (2014) explored the question of the quality-of-life history parameters found on FishBase. Two forms of data can be found on the website for life history: entered values and generated values. The authors indicated that the entered values were more accurate than the generated values. They describe a similar analysis comparing life history data on finfish, Teleosts, and Chondrichthyan species of fish. Seven life history parameters were studied relating to length, growth, age at maturity, and mortality rate. The authors provide suggestions regarding improving the quality of the data. This includes requiring authors who are submitting articles to the American Fisheries Society (AFS) journal to provide information relating life history parameters to FishBase at the time of article submission.

Biodiversity Heritage Library

Without access to past and present scientific literature, ecology and conservation knowledge will not flourish. Biodiversity information is dependent on knowledge of a large number of observations, experiments, field work, and laboratory work. When this literature is scattered across the world, expensive to accumulate, difficult to search, and moldering on dusty shelves, it hampers the conservation community from finding and identifying the information they need. The Biodiversity Heritage Library (BHL) was founded to address this need. They are dedicated to collecting and digitizing scientific literature in the public domain and pursuing creative commons access to more recent literature all to make this information widely available to scientists interested in biodiversity information.

BHL was established in 2006 as an international consortium of institutions containing collections of scientific literature that included biodiversity information. According to Kalfatovic and Costantino (2018), the BHL was established with the goal of, "The advancement of knowledge about life on the planet—its origins, preservation, and loss of species and environments—is no less dependent on access and reference to library collections" (p. 1). As of 2018 the BHL had become "a key contributor to the world of global digital library development" (p. 1). With the aid of 40 Members and Affiliates and more than 80 partner contributors the BHL had formed an open-access biodiversity literature collection that had digitized over 229,000 volumes. The collection contains literature ranging from the fifteenth century through the present day.

As of 2021 the BHL had digitized over 60 million pages of literature. This massive collection requires significant metadata to be searchable. Mozzherin (2021) has indicated efforts being made by the BHL to make taxonomic information more searchable. Examples of these efforts involve attempting to address the use of abbreviations for scientific names, and dealing with misspellings, and synonyms. To make full text searching for organisms more accessible, work has been done to provide taxonomic metadata on every record; however, the massive quantity of material hosted by the collection slows down these efforts. The BHL is dedicated to constantly improving the contents of its online collection. According to Keamey (2021), they currently collaborate with the Internet Archive, which has augmented the BHL collection through its extensive digitization efforts.

Preserving Ecological and Conservation Knowledge

FishBase and BHL are two knowledge products that provide important services to the scientific community. BHL helps make scientific literature easily available online. FishBase offers information about fish integrated around species identification that helps draw together a range of parameters that inform the scientists about life history traits. This is only a sampling of the products that allow the community to develop the necessary ecological understanding on which to build effective conservation strategies. There are additional products that scientists use as tools for analyzing, interpreting, and aggregating data (Sarinder et al., 2010). If this interpretation and aggregation is not recognized in scientific results, then the meaning of the data will be misunderstood. The data must be preserved as well as the means to analyze the products that helped scientists reach their conclusions; these products will be considered within the analytical section of this thesis. A further step in preserving scientific knowledge is recording aspects of community practice. For instance, when scientists go out in the field they use procedures that are taught within the field that are not always fully described within scientific papers. It's not enough to preserve the documentary products of the scientific community to fully comprehend community expertise but aspects of field practice and other means by which information is gathered and interpreted are also important for understanding the communities' knowledge.

The scientific community is attempting to build a larger range of resources to speed the process of discovery and application of existing knowledge. Some of this work is taking place within the scientific community, and some of this work is taking place within collaborative projects between scientists and information specialists (Adams & Bullard, 2014). These products need to be preserved and built upon to advance scientific knowledge. Additional products will be required to meet emerging needs. If the expertise of the community is to be preserved, new means of recording that knowledge will need to be identified.

Chapter Two: Literature Review

There is an active discussion within the biological community regarding the preservation of natural history knowledge. Natural historians are concerned about the loss of information that they perceive is happening within their community. This conversation is relevant to similar issues being discussed within the library studies community. However, the two communities have different vocabulary and different ways of discussing these topics. This is a common phenomenon across academia. Various disciplinary groups develop specialized rhetoric to carry on conversations within their community. Even though people across various disciplines frequently face similar challenges, they often don't know how to communicate effectively with each other because the norms of communication are uniquely established within each discipline. To facilitate communication, it is necessary to identify similarities and differences between the discussions of both groups. The literature review within this chapter will provide such a comparison between the discussion occurring within the biological community and within archival theory and other aspects of library science.

The literature review will begin with a discussion of how the concept of shifting baselines relates to the discussion within the archival community of the concept of archival memory. To make up for the insufficiency of the scientific record, ecologists have been borrowing data from other sources within the archival record. Ecologists have recognized the value of historical and economic records. This has significant implications for archival practice. Interdisciplinary projects within the archive present unique theoretical challenges. Ecologists are unaware of the theoretical discussions among archivists relating to the sort of use they are making of the archival record. If these discussions can be translated across communities, ecologists can potentially benefit from the knowledge of the archival community.

Archival Memory and Shifting Baselines

In a review of archival theory and aspects of memory, Hedstrom (2010) discussed current understanding of memory studies and pointed out ways archivists were drawing from this new work to advance archival theory. Hedstrom claimed that the archival community was struggling to articulate what was still an ill-defined relationship between the archives and memory. Memory studies offers a richness and breadth of ideas; however, at the time of Hedstrom's writing this new discipline was still working to define its identity and articulate its terms. In the discussion of collective memory, scholars use the archive as a metaphor, and the archive also serves as a physical location for the storage of collective memory. Hedstrom raises the question of the role archives and historical evidence play in shaping the debate about history/memory. Within the context of the discussion of the relationship of traumatic memory and history a question arises about how to respond to loss of memory. In response to individual and collective memory loss associated with traumatic historical events, some scholars have initiated memory reconstruction projects. Witness testimony can provide an invaluable source of evidence in the reconstruction of traumatic memory, but such evidence is not always available. Hedstrom offers witness testimony as an alternative source for reconstructing collective memory in response to repressive regimes when documentary evidence has been distorted. The debate about traumatic memory expressed by Hedstrom offers significant insights to the meaning of unrecorded evidence within the context of degraded ecosystems and communities when scientists have failed to record habitat loss and species depletion before the system was substantially degraded.

Hedstrom observes, “Memory remains problematic in historical scholarship precisely because of the apparent dynamic between present needs for a useable past and the evidentiary foundation on which historical understanding is built” (p. 170).

Memory studies has influenced archival appraisal practices, stimulating historians to seek a wider variety of sources when new needs arise as new historical topics emerge. Archivists find the need to expand acquisition goals and policies in response to these new needs. Hedstrom mentions losses associated with the archive, some having to do with the role archivists play in shaping collective memory, and some having to do with deliberate suppression of documents by oppressive regimes. What she fails to mention is how to respond to the problem of things nobody has ever taken notice of. This is the problem faced by the marine conservationists when they study degraded marine communities. The response of the marine conservationists has been to turn to the archives of other communities in the hopes of reconstructing a past marine scientists have failed to record. This has been the result of building on Pauly’s (1995) observations of shifting baseline syndrome. The work of Hedstrom in describing the relationship between archives and collective memory frames a similar discussion to the one taking place in the marine conservation community; however, she does not fully address the problems they are facing. Instead, the work of Jackson and colleagues (2011) to help establish a new subdiscipline of historical ecology has been constructed to fill in this gap. These two debates are taking place in isolation from each other. The archival community can offer insights to the marine conservation community, and the marine conservation communities’ attempts to meet their information needs presents a new case study in the limitations of the archive. It would be beneficial to bring these two communities in dialogue with each other.

Schwartz and Cook (2002) have argued that there is a growing awareness within the library science community that the role of the archivist is more than that of a mere functionary and that the actions taken by the archivist have the power to shape memory and identity. Therefore, the archive represents a site of power. Archivists have traditionally been viewed as record keepers. The records have been viewed as self-explanatory products; consequently, meaning lies within the records alone not in how they are handled. However, the role of the archivist shapes the way records are understood. The authors state,

> Archives - as institutions - wield power over the administrative, legal, and fiscal accountability of governments, corporations, and individuals, and engage in powerful public policy debates around the fight to know, freedom of information, protection of privacy, copyright and intellectual property, and protocols for electronic commerce . . . archivists - as keepers of archives - wield power over those very records central to memory and identity formation through active management of records before they come to archives, their appraisal and selection as archives, and afterwards their constantly evolving description, preservation, and use (p. 2).

If archives are a source of power, they can reshape society. Harris and Merrett (1994) argued that the public right to access to official records is a defining characteristic of democracy. This bold statement was made within the context of the transition of power from apartheid to greater democracy in the South African government. The authors state, “Knowledge does not equal power, as the cliché would have it, but power cannot be exercised without it” (p. 681). Due to the secrecy that existed under apartheid, Harris and Merrett state that to ensure democracy citizens need access to records to scrutinize government activity. The work of the authors is about more than the expression of culture and power, they are interested in promoting social justice. They argue that protecting the archives from the manipulations of oppressive regimes allows marginalized people to use the archives to protect their rights.

There are issues within fisheries management about the access of indigenous people and economically disadvantaged populations to fisheries resources that have garnered considerable attention of scholars studying fisheries issues in the last couple of decades. Fisheries management impacts economic and social rights. In a paper about indigenous fishing rights Plaganyi and colleagues (2013) state that maximum economic yield has been used as an increasingly important factor in determining fishery policy, which is achieved by a more conservative catch level than maximum sustainable yield. The authors focus on the need to manage fisheries resources in a way that takes into account problems associated with biological sustainability, economic needs, competing interests of various human populations including indigenous peoples and inhabitants of developing countries, and sociological factors. They advocate a holistic approach in their study. Plaganyi and colleagues indicate that over 78 million people in developing countries depend upon small-scale fisheries to support themselves. Working from the example of the tropical rock lobster fishery (*Panulirus ornatus*) of Torres Strait, located between Papua New Guinea from Australia, the authors attempt to examine the needs of local indigenous populations in relationship to the entire fishing community in the region. This article recognizes the needs of indigenous fishermen are both economic and social.

Conservation concerns cannot always be disentangled from the pressing subsistence needs of local fishing communities and are often aggravated by other environmental hazards. According to Albert and Isife (2014), fish represent one of the most accessible high protein foods available to impoverished populations in Nigeria. As a result, people in fishing communities along the southern coast of Nigeria rely on fish as an important food source. However, the impact of climate change has caused a decline in reliable fish catch and an increase in fishing hazards. Environmental degradation associated with climate changes such as sea level rise, changing wind patterns, increased storm strength, and changing precipitation patterns in addition to increasing acidification of the ocean has further affected fisheries and aquaculture.

Documenting the fishery management needs of indigenous populations and economically disadvantaged people has meant that fisheries managers and scientists are needing to draw on new sources of evidence. Not all of the evidence is scientific, and the archive has become increasingly important as a potential source of cultural evidence and a place to search for other novel sources of information. For users unfamiliar with archives the task of finding the material they need can be more difficult than finding material within the academic library setting. Scientists who attempt to make use of archival sources face multiple challenges. Because archival sources have a comparative lack of coherence, it can be difficult for scientists to find what they are looking for even if the information exists. Compared to searching scientific literature, archival searching requires new search skills. These difficulties mean that finding material can require a more intensive interaction between the patron and the archivist than is required in the typical library setting (Duff, 2010).

The problem posed by serving the fisheries management and conservation needs of indigenous populations and developing nations raises the issue of access. Marine conservation is a global issue that has complex local consequences. Environmental and social settings are unique through communities across the world. How do you serve a community that is at once global in scope and very particularly local in character? This is a question that cannot have a perfect solution, but it may have a best available solution. The suggestion of this thesis is the promotion that community archives about local conservation, taxonomy, and social factors should be gathered and digitized to promote global access to the particular records of each community.

Non-Western people have their unique cultural interaction with nature. The Australian native from the Koorie people, Shannon Faulkhead (2010) studied the contribution to knowledge made by indigenous Australians. Faulkhead claims that cultural communication does not exist in a single form; she emphasizes that at least two forms of communication are always taking place through orality and the production of textual records. When the archives privileges textual records over oral ones, less literate cultures are frequently overlooked. The indigenous community is an important source of knowledge.

An increasing amount of scholarship in the past decade or two has attempted to assess the participation of indigenous peoples and developing nations in global fisheries. This is information that hasn't been recorded before, and it requires a group of multidisciplinary scholars to take an ethnographic approach to gathering information. They have largely relied on oral interviews in conjunction with observations of fisheries technologies and practices and archeological evidence (Amaral, 2005; Dale & Natcher, 2015; Giovas, 2021; Grydehøj & Ou, 2017; Caorthers et al., 2021; Kitolelei, 2021; Menzies & Butler, 2007; Schnierer, & Egan, 2016; Richmond & Kotowicz, 2015; Senapati & Gupta, 2014; Sobreiro, 2015; Sutherland, 2021; Walsey & Brewer, 2018; Williams, 2008). A new genre of scholarship is emerging around the issue of indigenous fishing rights and traditional fishing practices. This literature is important to the marine conservation community since it will allow conservationists to consider the needs and opinions of people from these communities when determining fishing rights. This material is particularly local in character, but the implications are global. It raises the issue of how this new data will be accessible to the people that it impacts. Indigenous peoples rarely have access to scholarly literature unless it is published on an open access platform or can be found in locally accessible archives. With scholarly literature frequently hidden behind paywalls and dispersed in academic journals, only indigenous people who are part of the scholarly community are likely to find this literature.

It has been suggested that an appropriate solution for accommodating the information needs of marginalized populations is to provide spaces such as community archives to create a place where their voices can be heard. Poole (2019) provided a review of the literature on community archives that characterizes the debate on the subject. Poole reviewed over three decades worth of material on the subject ranging from 1985-2018. He found the literature covers a wide range of geographical, topical, and disciplinary themes. The issue where this literature most closely intersects with the problem of indigenous fisheries is covered by Poole's third theme that includes a discussion of political empowerment, activism, and social justice. He indicates within this context that control of the archive promotes political power. Harnessing the information of a community archive allows the activist to do information work, guide action, preserve memory, allowing the community to reclaim their place within the larger social network. By preserving the scholarly work on indigenous fisheries in a way that the communities concerned could access has the potential to allow these people to better protect their fishing rights, their access to resources, their economic and social autonomy. Societies that have a long tradition of subsisting on local resources have sometimes found themselves the losers of colonial governance of local natural resources.

An additional theme that Poole (2019) raises that relates to the needs of indigenous communities is that community archives frequently include nontraditional records and artifacts.

The scope of research associated with indigenous fisheries includes information that goes substantially beyond the scientific record. Putting the information gathered about the indigenous community back into their hands allows more active participation in how the community defines itself as a social entity and a user of natural resources. "Another reason to preserve records digitally is to create space for memory of groups that have been underrepresented, and who have been traditionally left out of curation sites like museums and academic archives previously" (Ahlfeld, 2021, p. 494). Freely available online access to information about indigenous fisheries would allow underrepresented communities around the world to better understand local concerns within the larger global context. Such community archives would also provide an invaluable source of information to the marine conservation community and allow for more equitable management of fishery resources.

Global Access to Fisheries Information

The issue of indigenous fisheries highlights the dual character of fisheries' data. For each indigenous community fishing is a particular and local phenomenon. But natural resources issues are global issues. The use each community makes of local natural resources has effects that impact the larger environment. The more that is known of fishing activity both on the local and global scale, the more the genuine impact of fishing can be assessed on the variety of scales through which it is monitored. However, incomplete information regarding the range and extent of fishing activities across the world hampers this understanding. The scientific community is already grappling with the absences and biases of the historical record. This problem is compounded by the difficulties associated with accessing proprietary information. For decades the rising costs of institutional subscriptions to journals have outpaced inflation, meaning even prestigious universities are balking at maintaining subscriptions to some academic journals (McLellan, 2004). Not every institution can afford subscriptions to the numerous journals in which the large amount of environmental, ecological, fisheries, historic, and oceanographic information that describes the functioning of marine ecosystems resides. Effective fisheries management and conservation is hampered by failure of access to all the relevant information necessary to protect the marine environment. Due to access barriers even in academia, when easy solutions are not provided, scientists have been adopting a make-do attitude accessing the information most readily available rather than striving to find the most relevant information (Worsley, 2019).

Libraries have attempted to bridge the gaps associated with limited information resources through instituting services such as interlibrary loan. However, not all relevant information is distributed within the scientific literature. Scientists have had to explore archival resources outside the information resources of the scientific community. To facilitate adequate access to information scientists would be aided both in an increase of access to open access scientific literature and the digitization of historic records. Additional work must be done in making available grey literature produced by governmental institutions and university presses.

A factor that can facilitate understanding of the issues that shape marine ecosystems within the conservation community is the availability of open access data. When institutions and individuals freely publish their research online, scientific communication is enhanced, and the community has greater opportunity to share in the necessary knowledge to understand the state of the field. In a domain analysis relating to the marine environment Sahoo and Pandey (2020) have noted that the global scientific community is increasingly embracing the utility of publishing on open-access platforms. Additionally, authors can independently choose to make their research available by posting their papers online and providing creative commons licensing. In an environment where researchers are becoming increasingly dependent on online searching outside libraries and other institutional resources, the communication of information will become increasingly shaped by what information can be found freely available online. Institutional or discipline specific repositories serve as another source of open access material. Additionally, the discoverability of material in search engines such as Google will further shape what is perceived as representative of the knowledge of the scientific community.

A frequently overlooked resource that must also be considered relating to environmental problems and resources is that of grey literature. Grey literature includes scientific information frequently found in publications by governmental institutions, contracted projects, and by universities that is published outside journals and other peer reviewed sources. For example, Costello (2007) recorded progress on the Louisiana Coastal Grey Literature Project. The Louisiana Governor's Office prioritized saving this literature that had been collected over 70 years that documented coastal erosion. Over that time the Department of Natural Resources had gathered evidence that Louisiana had lost over 1,900 square miles of coast land due to erosion. During this project librarians found that, "Many of the agencies had libraries that were no longer staffed and had not been actively collecting materials for many years" (p. 22). Project staff found that the condition of some material that they located was almost too damaged for restoration and that other material was past saving. This project was disrupted by Hurricane Katrina, and although the paper was published and posted online, an internet search yielded no further evidence that this project has been followed up since that time.

A further grey literature research project by MacDonald and colleagues (2007) explored the impact of grey literature produced by the Gulf of Maine Council on the Marine Environment

(GOMC). Since 1989 the Council has produced information resources about marine environmental issues such as newsletters, conference literature, technical reports, fact sheets, and other material promoting knowledge of the marine environment. Starting in 1997 GOMC began producing some of its materials as PDFs that were freely available through their website. After evaluating the impact of this literature, the authors argued that the transfer of scientific findings was necessary for making effective policy decisions and that grey literature had to be taken into account through the process of knowledge transfer. The issue of grey literature is only occasionally addressed by the scholarly community, and additional searching yielded no more recent literature describing the activities of the GOMC regarding grey literature; however, the GOMC currently maintains an active website, and a brief investigation of the website indicated that they are still posting PDFs of their material freely available online.

The Living Archive

As marine ecosystems are facing increasing perils due to habitat loss, species decline, loss of resilience, and ecosystem disturbance, the conservation community itself is facing a communal loss of knowledge. Natural history knowledge and taxonomy are subjects that have faced declining funding for decades. The memory of the community is failing. In a paper articulating the need for natural history knowledge to effectively understand the factors necessary to conserve marine ecosystems, Dayton (2003) raises the alarm that this critical knowledge is being lost by the community of science. Dayton states,

> A sad commentary is that our ability to respond and to defend natural systems has been eroded within academe by scientific elitism against natural history and systematics. Biology undergraduates increasingly have little opportunity to learn classic zoology or

> botany, invertebrate zoology, mammalogy, herpetology, ornithology, ichthyology, and so forth. Many first-year graduate students do not know the major phyla or the life history—and sometimes even the anatomy or developmental biology—of their own study organisms. Unfortunately, the study of minor phyla is a thing of the past. Without this grounding, it is no wonder that the respect for natural history has been lost despite the fact that this grounding seems vital. In almost all cases, we lack appropriate natural history to evaluate relationships and population thresholds, and we have lost virtually all instruction in taxonomy; it is a poignant paradox to lose biodiversity while simultaneously losing the scientific knowledge base of what it is (pp. 10-11).

The community itself is a critical repository of knowledge. Not everything that is known by the community is ever transmitted in print. Some aspects of knowledge are communicated through practice and in other nonverbal forms. If knowledge isn't actively retained within the community, some aspects of the knowledge will become lost in such a way that the community itself will never be able to replace it, though they may be able to reconstruct a new version of the lost knowledge.

In an earlier paper by Dayton and Sala (2001) that explores scientific creativity, the authors express similar concerns to Dayton's 2003 paper about the loss of natural history knowledge and the failure of financial commitment by the scientific community to observational natural history. Sala's work demonstrates the importance of working with skill mentors, since he served as a postdoc with Paul Dayton. Sala has gone on to become a leading voice in conservation. The paper expresses the importance for emotional engagement with nature as part of understanding the soul of ecology. The authors speak to the critical issue of values within scientific practice claiming that values are taught by practitioners. They argue that learning values is process that requires personal engagement between a student and a mentor.

Human knowledge is intuitive and sometimes not articulated. There are aspects of it that escape our capacity to express in words, but this knowledge can still be learned and passed on from generation to generation. The traditional archive can never hold the full scope of communal knowledge. Only a sustained community can do this. In my reading of the literature of archival theory, I have not yet come across anyone that has expressed this concept in quite these terms, but my reading is far from exhaustive so I can't be certain that no one has already said this. But as long as there is an active community of knowledge, there is a living archive that contains information that will never find its way into the documentary archive. In addition to what is inarticulate, a community of knowledge has an informal communication structure that means that a lot of knowledge is passed on in undocumented forms.

There are aspects of my own knowledge of marine ecology that are hard to document. I am not extensively trained in marine ecology. I have a B.S. in Biology in which my concentration was Marine Biology. I also have an M.S. in Oceanography in which I studied Biological Oceanography. My true specialization is history of science, and in this field, I hold both a M.A. and Ph.D. I also spent five years as a database editor, where I indexed aquatic science abstracts, but I have never worked professionally as a marine ecologist. But there are things that I know based on conversations and classroom experiences that I have had over the extent of my scientific training that shape my understanding of the marine environment. I write of this because I need to emphasize the importance of informal communication that happens within the community of scientists. An example of this informal communication is the awareness I have of the importance of habitat structure within the aquatic environment for attracting communities of planktonic organisms and small fish. This is something that I had thought was common knowledge because I had heard it repeatedly spoken of in more than one classroom setting two decades ago. However, I recently located a paper, Shaffer and colleagues (2020), that spoke of this phenomenon as an unconfirmed observation.

Without adequate access to the living archive, the community is doomed to have to continually relearn what older members of the community already knew by returning to the more drawn-out process of making original observations or digging up material from the archive that nobody told them was there. People don't know how to look for knowledge that they don't know exists and don't even have the terminology for. What search terms can a scholar use to look for gaps in their knowledge? But this community is dying, because the education system had devalued their knowledge to such an extent that new graduate students are not being trained to replace their knowledge of natural history and systematics.

Paul Dayton is retired, but he continued to write about his research and experiences long after his official retirement. In a recent paper Dayton (2020) wrote an intellectual and biographical account of the development of his ideas about science, conservation, and the need to educate future scientists and the public about ecology and conservation. Speaking of his youth Dayton recounts his acquaintance with scientists associated with the University of Arizona. He recounts the development of an aspect of environmental history of the desert where a desert ecologist compared old photographs with recent photographs to study change in the desert. Dayton indicates that, "This too resulted in a growth industry of scientists extracting valuable data from archived photographs" (p. 1649). While describing his research, Dayton makes the observation that people communicate and remember lessons through storytelling. This paper is offered as a retrospective of Dayton's career. Discussing some of his successes and failures he addresses scientific values, considers the importance of ecology, and emphasizes the need to educate the public about nature.

There is more being learned by working ecologists than is easily conveyed in scientific literature. The data is only part of the story. Dayton's paper (2020) draws out some of this experience. His discussion of working in the field attempts to articulate the process of integrating an understanding of nature that comes with developing a feeling for nature. There is an aspect of this experience that can only be communicated within the field. Dayton discusses the importance of taking students who are not necessarily pursuing careers in science into the field to help communicate to them a greater love and understanding of nature.

The marine scholars pointed out in the opening chapters of this thesis, Daniel Pauly, Jeremy Jackson, Paul Dayton and Enric Sala, serve as examples of aging ecologists and fisheries biologists who are irreplaceable to the conservation community. When they die it will represent a substantial loss to the scientific community. Though they have trained numerous students, they could not convey the extent of their knowledge, since the academic environment was reprioritizing the disciplines in which they worked. The best that can be hoped for is that these scholars and others like them will record as much of their knowledge for the future as possible. It's not possible to record everything they know because some aspects of knowledge are hard to communicate in written and verbal forms. But the more done to preserve their knowledge the better.

Field Biology

Field biology has changed in the centuries since its inception. This fact must be recognized since past data plays such a critical role in understanding how humans have altered ecosystems. Its roots draw from the rich field of natural history that was developed in antiquity. However, we need to look to the early modern period to develop a coherent narrative of the development of natural history that forms the basis for the modern practices on which field biology was derived from natural history. Natural history was developed in antiquity; however, the practice of natural history was submerged as an active field of investigation through the Middle Ages. Ogilvie (2006) traces the history of the reemergence of natural history through humanistic studies during the Renaissance in Europe. The knowledge we have regarding the state of global ecosystems during the early modern period is largely indebted to the growing interest in natural history from this time period. Thanks to natural history observations made by amateur natural historians and explorers, we do have records of wildlife documented during the age of exploration, that help reconstruct the way Europeans started altering ecosystems as they began to explore the New World (Roberts, 2007).

Haila (1992) identifies field biology as an important tool for the development of modern ecological knowledge. He indicates the historical nature of the objects studied in field biology and shows that by its nature it is an observational science. Change is imbedded in historical processes and as a consequence the same ecological situation does not occur twice. Attempts at replication will often yield varying results. This creates challenges for the development of quantitative techniques for measuring changes in nature. That hasn't stopped ecologists from attempting to quantify nature. The history of ecology in the twentieth century was largely driven by attempts to create scientific models of nature (Kingsland, 1995).

Ecology is further complicated by changes to ecosystems caused by human activity. Ecologists were not initially aware how much the systems had already been altered before they began to study them. But conservation cannot be understood until this change is acknowledged.

As Haila (1992) states, "The immediacy of history in field biology relates to yet another complication, in some sense the most difficult of all: humans themselves are historical agents who have shaped the only living nature we know" (p. 238). As a result, Haila indicates that it is imperative for history to be acknowledged as a factor of causation in conservation biology.

Two forms of data collection within field biology have particular utility to conservation biologists. The first is systematically collected data that field biologists record to uncover as yet unknown phenomena in nature. This data is less theoretically driven since generalization must be reserved until after data collection rather than before. For observational data to be classified as science, ecologists feel obliged to theorize the meaning of their data. But when too much theorizing occurs before collection, it can restrict the range of observations made and consequently overlook natural process that are critical for understanding how systems are changing. Observational data has been classified as second rate since the twentieth century as scientists attempt to use mathematical and theoretical methods to generalize nature. While Haila (1992) acknowledges that mathematics and theory are important tools in field biology, he also recognizes the importance of observation.

The second type of field data critical for conservation is data used for comparisons, "Because of the specificities of field biology, intelligent and theoretically justified comparisons are the closest we can get to testing in many situations" (Haila, 1992, p. 247). It is important to understand causation in ecology, but ecosystems are open systems and it is impossible to effectively test ecological processes in laboratories, which are by necessity closed systems. Comparison in the field is the closest ecologists can get to determining causal relationships.

Both Haila (1992) and Kingsland (1995) have acknowledged the impact that modern physics has had on the development of ecology in the twentieth century. Ecologists have borrowed theoretical and methodological ideas from physics. This has meant that ecologists have attempted to theorize about ecology in ahistorical terms, but modern ecologists such as Pauly (2019), Dayton (2003), and Jackson (2011) have shown that it is risky to forget history when studying conservation. Haila has pointed out that incorporating history into field biology shapes the kinds of questions ecologists ask. Critical processes in nature will be overlooked without recognizing that ecosystems are historical. Ecosystem are shaped by the long-term consequences of historical change. History introduces an element of indeterminacy that can't be quantified when using methods and theories when borrowed from physics.

If ahistorical methods are ineffective at describing ecological systems, why have physics models been so successful at colonizing modern ecological practice? Ironically, the reasons are historical. Nineteenth century natural history practice came under attack towards the end of that century as scientists attempted to adopt methods that were not as dependent on the institutional support of prestigious universities, large museums, and other imposing nineteenth century institutions. As a result, laboratory practice and experimentation were suggested as effective means of studying biological systems (White, 2003). This only represents one phase in the process of transformation. Further factors in the twentieth century also drove the transformation of science. During the Cold War U.S. scientists raised concerns that the country was falling behind in science education. They encouraged the implementation of new curriculum to encourage U.S. students to excel in the sciences. Government funding helped promote the development of that new curriculum. A team of physicists put together a new curriculum for students that impressed officials making funding decisions for the development of the project. This became the new model around which science educators wrapped the rhetoric regarding how good science functioned (Rudolph, 2002).

Scientists in charge of developing the new biological curriculum felt pressure to adopt the model developed by physicists. The biological curriculum was considerably less unified than the physics curriculum of the time. Committee members raised concerns that this lack of unification could push qualified students to choose more accessible fields of study. Government funding of research also drove curriculum development; for students to receive funding for their research they would need to conform to the kind of goal-oriented research projects that physicists could develop based on the new curriculum. Rudolph (2002) argues that the prestige of the physics curriculum attracted biologists to attempt to emulate their success by making their research programs more closely resemble physics projects.

Even before curriculum reform ecologists had been adopting mathematical modeling as an explanatory tool for understanding the results of experimental and field data (Kingsland, 1995). That trend has only deepened in recent decades and scientists have adopted more computer intensive statistical methods. Theoretical ecology relies heavily on schematic and mathematical models. But models cannot be tested without large amounts of population data and environmental data. Questions at the heart of theoretical ecology include population growth, demographic relationships, life history, reproduction, community interactions, geographic relationships, and environmental factors (Case, 2000). A successful strategy for understanding ecological communities will continue to rely heavily on basic natural history including field surveys of populations, observations of community interactions, and how organisms live and feed within natural landscapes.

The landscape is a kind of palimpsest that has been written on and erased many, many times. Traces of that past lie hidden both in the landscape itself and in the documents in which past observers recorded what they have witnessed. In some respects, the evidences of the past are irrecoverable. Knowledge of the past will always be incomplete, but through careful reconstruction of historical, scientific, archeological, paleontological, and geological sources, we can recreate some of that missing knowledge. The philosopher of science, Adrain Currie (2018) provides an analysis of the historical sciences in an attempt to explore the limitations of reconstructing the past. Arguing from an epistemologically optimistic perspective, Currie suggests that traces from the past can be used to help scientists better understand the present and the future. He draws illustrations from geology, paleontology, and archeology to make his case. Currie indicates that the historical sciences need to adopt omnivorous methods to achieve their goals of uncovering most effectively what can be uncovered about the past.

Though Currie (2018) does not directly address the topic of ecology, much of what he says is applicable to the ecological sciences since ecosystems function historically even as they are a present object of study. Ecology, paleontology, geology, and archeology all involve the study of the landscape, the primary differences between these disciplines are defined by the objects of study and the timescales they operate on. Currie indicates that historical systems can be studied though the use of mid-range theory to explain the meaning of traces, by using analogies, exploring the dependencies of past variables, and through the use of surrogates. If all of these means are genuinely effective techniques for the use in the historical sciences, ecology can add to this repertoire current field studies, scientific literature, and archival sources.

The factor that makes a science historical is a relationship where the present state of a system is dependent on the past. Historical systems are complex, so they can be difficult to describe, but that complexity is governed by causal processes. Trace data sets are gappy, but if enough information can be recovered it may be possible to construct a coherent narrative of the past. Two factors make the contingency of historical systems more fathomable if enough evidence can be gathered to take advantage of them, these are path dependency and sensitivity to initial conditions. If you know something about the initial conditions of a system, such as the carrying capacity of a top predator, an ecologist can unravel how an undisturbed system should function even if the current state of the system has been highly disturbed. (In fisheries determining the carrying capacity, that is how large a population an undisturbed system should support, is an important step in determining the state of the fishery). Currie (2018) explores these concepts within a different context, but it is possible to show the relevance of these factors to marine ecology and conservation. He states, "For an event to be path-dependent, then there must be multiple paths . . . and the probability of reaching an end state . . . changes depending on which path is taken" (p. 209). The work of attempting to understand the outcome of human disturbance on a marine ecosystem serves as an example of determining the path-dependency of the system.

Currie indicates that field work is expensive. He states, "historical science is often risky, expensive, and provides ambitious results" (p. 294). However, if conservationists are to have any hope of preserving fragile marine ecosystems, it is essential to have the data necessary to uncover how these systems work. Attempting to understand the past, trying to comprehend the present, and working to forecast the future is at the heart of ecological practice that conservationists need to manage the ecosystems across the globe. There is an element of uncertainty regarding how ecosystems work even when they are well studied and well documented. Where no data is available that uncertainty is insurmountable.

Conserving Uncertainty

Memory and knowledge are fragile. The debate about memory and the archive as well as shifting baselines shows that a lot of uncertainty exists regarding the past and the present. How can conservation work when there is so much uncertainty regarding the functioning of marine ecosystems and the status of fisheries populations? The domains of marine conservation and marine ecology are not well defined. The complex ways they overlap are not well known. In the analytical portion of this thesis a basic overview of how these domains overlap will be examined.

Chapter Three: Methodology

Introduction

Domain analysis is a product of the information science community that analyzes thought or discourse communities within the broader culture. In a series of articles, Hjørland has defined the nature of domain analysis and given advice on how it should be done. Hjørland (2017) has stated that domains exhibit a dual nature that has both an intellectual organization and social organization, and as a result, domains develop a characteristic knowledge. It should be noted that many domains use overlapping vocabulary, however, the meaning of the terms shift from one domain to another. This means that information specialists who are not familiar with how the vocabulary is used in various domains and disciplines may misclassify metadata if they don't have a specialist vocabulary for technical language within a given domain. It can take years of study and practice within an academic domain to develop the vocabulary to adequately describe the knowledge products of scholars.

Hjørland (2017) raised the issue of who is competent to perform a domain analysis, because it was something that was being debated in the literature of LIS. The question at stake was whether domain analyses need to be performed by the initiated few or whether generalists have the competence to perform domain analysis as well. He indicated that domains can fall into two categories. In the first category he placed knowledge that already has well established languages, division of labor, and have already been formed into distinct academic disciplines. In the case of these disciplines the conceptual distinctions have already been well formed, and the domain analysis of these disciplines is best performed by those with adequate subject knowledge outside of information studies to recognize the factors that define the domain. But Hjørland acknowledges that there are still domains that are less stable or can at periods in their development be susceptible to change from inside or outside their community, and these domains still can be open to definition or redefinition. He doesn't clarify if in this case domain analysis should be performed by an insider, and it is likely that this should be decided on a case-by-case basis.

Smiraglia (2014) provides an overview of domain analysis including both a definition and a description of common techniques used in performing domain analysis. He indicates that domain analysis is a mixed methods approach making use of both qualitative and quantitative data. Citation analysis is a technique commonly included in domain analysis allowing the investigator to quantitatively explore citation practices within a field. Co-word analysis depends on the use of software that can provide numerical and graphic representations of the frequency of the use of important words within a text, a range of variations of automated text analysis have been used by researchers (Ignatow, 2015). Author co-citation analysis examines similarities in citations between two authors who are doing work on similar material and allows the analyst to visualize similarities and differences in citation practice. Network analysis also allows for visualization that maps relationships between objects in a data set. Cognitive Work Analysis (CWA) borrows from ethnographic research to map interactions within a community. The results of domain analysis can allow information specialists to develop controlled vocabularies and classifications to describe this work.

The range of techniques for domain analysis described by Smiraglia (2014) cannot by themselves meet the needs of the scientific community to fully describe domains. The domains of scientific subjects can be broad. Biology represents a very broad and complex domain. The scope of biodiversity and the complexity of ecological interactions determines that only methods that allow researchers to define the scope of knowledge will demonstrate the range of material that characterizes biology. Only through the use of creative approaches will a broad range of a domain such as biology be adequately described. This applies to marine ecology and conservation as well.

Rothenberger and colleagues (2020) attempted to take an interdisciplinary approach to the practice of marine ecology by adapting the concept of a domain analysis to three types of data from marine ecology: standard ecological monitoring, online-reporting databases, and fisheries surveys. The study attempted to integrate public reporting as a form of citizen science with scientific survey data because funding limitations meant that inadequate scientific data had been accumulated to monitor the ecological disruption associated with two invasive species, the Asian shore crab (*Hemigrapsus sanguineus*) and Chinese mitten crab (*Eriocheir sinensis*). The authors used data visualization techniques drawn from ecological monitoring. By integrating data from the three unique survey types the authors were able to demonstrate the range of species invasion was larger than would have been known if only the scientific data was used. They used techniques borrowed both from ecological monitoring and from sociological surveys, which required a creative approach to integrating data and yielded more accurate results from monitoring the environmental disruption of the invasive species. This study does not fall under the purview of a traditional domain analysis, but it should not be overlooked as it demonstrates both the needs of the conservation community, and the way interdisciplinary work needs to adapt variations on traditional research methods to new information needs.

Sahoo and Pandey (2022) performed a bibliometric study of the subject of ocean acidification. Their work identified the most influential papers in the field and the geographic distribution of their production. Oceanic acidification disrupts the physiology of plankton, molluscs, and corals and can also affect photosynthesis. In addition to the domain analysis the authors conducted a thematic analysis of prominent keywords. The use of keywords allows researchers to search a large number of records. Some of the techniques used in domain analysis rely on distance viewing of texts; that is, when statistical information is gathered on texts through activities such as keyword searching without reading the full textual material. This allows those performing the analysis to examine larger quantities of material than would be possible if the analyst were systematically reading the literature of the domain. Some subjects generate such a large quantity of literature that systematic work is impossible if an analyst is attempting to characterize the full range of the field. However, in the case of this thesis the work I am attempting to do cannot effectively be accomplished through distance viewing. Distance viewing assumes that the analyst knows what they are looking for. In the case of this project, I am attempting to characterize the range and scope of knowledge products that conservationists use within the field of marine studies. Ecology and conservation are abstract fields that cover many concepts, and a person would have to compile a prohibitively long list of search terms to try to analyze the field. Even if this were accomplished, even a highly trained subject specialist would be unfamiliar with some concepts within the field. As a result, the best approach for this work is to perform a systematic analysis of the literature.

Methods

The method chosen for this study is domain analysis of marine conservation that focuses on identifying the knowledge products necessary to maintain continuity for future conservation work. Scientific literature is developed from a large quantity of data and additional knowledge products that are not preserved strictly within the confines of the literature. It is not adequate merely to preserve the literature if future generations are meant to build on previous studies that describe the aquatic environment, the communities that inhabitant them, populations of at-risk species, and the field studies conducted by previous conservationists and ecologists. This study will be conducted by creating a list of standardized terms identifying the form of the knowledge products studied within the literature. The creation of standardized terms is necessary for completion of statistical analysis on the nature of the knowledge products identified. It is only through the aggregation of a large data set of standardized terms that a statistical portrait can be developed of the type of data necessary to conduct conservation studies. Since no similar study has been conducted, these terms will have to be determined at the time of study.

Prior to writing the literature review, I attempted to determine if any previous study of this kind had been done. I completed a union catalog search in the University of Oklahoma main library search page on the terms "domain analysis" and "marine ecology" and came up with 23 hits. After examining the titles, I came to the conclusion that none of the articles were relevant to my search. A second search of the four terms domain, analysis, marine, and ecology yielded 132,178 hits. The first hit was a more recent article by the authors of a paper that I already had (Sahoo & Pandey, 2022). I browsed the first 20 articles, and only found one other paper of possible relevance (Rothenberger et al., 2020). Next, I completed a search in the *Library Literature & Information Science* database using the terms "domain analysis" in the first selected field and "marine ecology" in the second selected field. This yielded only two papers, both of which were from the same authors I had already located (Sahoo & Pandey, 2022; and Sahoo & Pandey, 2020). A general search of the term "domain analysis" yielded 165 results. I browsed the titles of all 165 articles but didn't find anything resembling the project I was preparing to work on. I returned to the union catalog and tried a half dozen additional combinations, and the initial search results yielded nothing interesting. I completed a search of "domain analysis" in

Proquest's *Natural Science Collection.* The search yielded 19,242 hits. I examined the first twenty results, but the articles did not resemble LIS material. The literature was mostly technical and had to do with subjects such as electricity, computer science, and physical sciences. The search "domain analysis" and "marine ecology" yielded 40 results. In these cases, the term "domain analysis" appeared to be used in the context of genetic and molecular sequences and geographic and paleontological distributions and was not being used in a way similar to the LIS term "domain analysis." Next, I tried Elsevier's *ScienceDirect*. The keyword search "domain analysis" yielded 25,581 hits. A search of the first 20 hits yielded one article of apparent relevance (Jung et al., 2022). The search "domain analysis" and "marine ecology" produced 13 hits, but no additional articles of relevance. Upon reading the articles I found, it was clear none of the papers closely resembled the analysis I will be attempting in this thesis.

For my domain analysis I selected the journal *Aquatic Conservation: Marine and Freshwater Ecosystems*. I selected this journal, since it is the only journal I am aware of that specializes both in conservation and the aquatic environment. There are numerous journals that specialize in marine ecology, and there are also a large number of journals on the subject of conservation. Many of the articles within these journals would be outside the domain of marine conservation. Since *Aquatic Conservation* includes articles both on marine and freshwater ecosystems, even this journal contains articles beyond the scope of my research. Nonetheless, the techniques and knowledge products relevant to freshwater ecosystems should be closely related and should be of interest to marine conservationists and ecologists. At the time I began this study, the Wiley subscription that OU had for this journal only had articles available for full text browsing through 2018, excluding access to the most recent three years of research. The website does allow viewing of article titles and abstracts up to current publication dates, but full text articles are frequently viewable only by paying a substantial fee or purchasing an individual subscription to the journal. Some recent articles in *Aquatic Conservation* are designated open access.

Ideally a domain analysis attempting to describe the scope of material for a field such as marine conservation would examine a very large number of papers. A minimum recommendation would be to examine five years each of material from over a dozen journals. If the most influential journals were identified for both marine conservation and marine ecology, with an emphasis placed on the overlap between these subjects, this would present the most effective strategy for performing a domain analysis. However, this is a master's thesis, and the time constraints of a project such as this limit the amount of material that can be examined. For this reason, only one journal was studied for this domain analysis. The time constraints further restrict the time range that can be covered. Three years of articles were examined for the domain analysis ranging from 2016-2018 since full text viewing is not available past that date.

The material I looked for could not be identified without reading the full text of the articles. The purpose of this research was to identify the range of knowledge products used by marine ecologists and conservationists. I had no foreknowledge of the full scope of these products, and not all of the relevant information will be contained in the abstract and title of the articles. For this project I read all of the full length research articles from every issue of the years examined. Statistical information was gathered describing the knowledge products that the authors relied on for their research. When all of this data was collected the statistical information was presented in table form.

To better describe the technique for this study a small learning set of articles was selected from *Aquatic Conservation*. An identification number was employed to describe each paper using the publication year, volume number, and issue number to uniquely identify each article. After the identification number, the term "habitat" identifies whether each ecosystem studied is primarily marine, brackish, or freshwater. The term "category" is used to provide a brief description of the type of research being conducted within the paper. The next term is "geography," and it is meant to describe the location of study at the level of country or oceanographic feature. There is also a brief description of the "methodology" of the paper. Each "knowledge product" used within the paper is identified with its unique line. The object of this study was to perform statistical analysis of the knowledge products being generated or used by biologists. In order to do this a consistent vocabulary had to be developed to name all knowledge products that were similar in nature. I developed a controlled vocabulary to describe the knowledge products. The use of this controlled vocabulary was different from how librarians typically use controlled vocabulary, since its primary purpose was to simplify statistical aggregation rather than to search the papers. These terms were developed in the process of reading the papers and reflected the vocabulary used in this research.

Since there are multiple knowledge products used in most papers, statistical analysis reflected a considerable amount of overlap within this set. In the course of analyzing the learning set, it became clear that certain categories of knowledge products would need to be further broken down into subcategories. The example that most frequently presented itself in the learning set was the use of the category "population data." In this case a very brief analysis yielded the following subcategories for population data: numeric, taxonomic, reproductive, morphometric, geographic, genetic, and demographic. In addition to data, various forms of software that were used to analyze the data were included for the reasons discussed in the paper. The general type of the software is to be identified, and the name of the product is included as a subcategory. The described terms are the full range of coded vocabulary that will be used to identify the content of these papers for the purpose of the domain analysis.

This project is meant as a survey to inform the library science community and the marine conservation community of the range of material that needs to be conserved to maintain disciplinary coherence for the practice of marine conservation. Marine conservation is informed by marine ecology, but the classical methodology of marine ecology is in decline. Marine ecology is a complex field, that cannot be easily preserved without a careful analysis of what constitutes the domain of marine ecology and how the domain of marine ecology interacts with the domain of marine conservation.

Chapter 4: Results

Aquatic Conservation

The first volume and issue of the journal *Aquatic Conservation: Marine and Freshwater Ecosystems* was published in September 1991. Because it was already the fall when the first issue came out, there was only time to publish two issues that year. The first issue contained only three full length research articles and one short communication. Other sections in this issue included: Viewpoint, Book Reviews, Meeting Report, Conference, and Announcement. The sections contained in the journal vary from issue to issue depending on the available content. The second issue from December 1991 included four full length research articles and two short communications. So, in total seven full length research articles were published in 1991. In 1992 four issues of the journal were published and a total of 15 full length articles.

In the 25 years between the launch of the journal and the publication of the content examined for this research project, contributions had grown substantially. The first volume analyzed for this project was volume 26 for the year 2016. By that time *Aquatic Conservation* had moved to a bimonthly publication schedule. In addition to the six standard issues published that year, the journal also included two special issues. Not all the full-length articles published that year were research articles. Volume 26, issue 5 was a 25-year anniversary issue, and instead of publishing original research the editors teamed up and wrote a series of review articles with the aim of discussing how the field of aquatic conservation had advanced in the 25 years since the publication had been launched. The two special issues largely addressed policy matters, so many of the articles within these issues reviewed policy, rather than presented original research. Because of the structure of this project, only the articles within these special issues which were research articles were included in the statistical analysis. Policy articles do not produce original data, so there was nothing to record. However, since policy still represents an important aspect of the of the domain of marine conservation, a qualitative discussion of the second special issue is included in the results section. The anniversary issue was also considered in qualitative terms since the rapidly changing nature of science also represents an important topic. Although the research articles from the first special issue were included in the overall analysis, no qualitative discussion of this issue is included in the results chapter since the focus of the issue was strictly on freshwater conservation.

Volume 27 also included a special issue as well as the six standard issues. The majority of the articles in the special issue were also oriented to a discussion of policy, the three research articles within this issue are included in the statistical analysis, but as in the case of the special issues from the prior year no data was included for policy articles. This special issue addressed an important aspect marine policy, and a qualitative description of this issue is also included in the results section. There were no special issues for the year 2018, so all full-length articles within volume 28 are included within the statistical analysis. For the three years considered in this analysis 320 full-length articles were published. Of these 39 were excluded from the statistical analysis since they were either review articles or policy articles. In total 281 full-length research articles were published between 2016-2018. These articles constitute the dataset on which the statistical analysis of data produced by the authors in this journal is based.

In the course of the analysis of the journal, a controlled vocabulary was developed to describe the data being produced and the tools being used by the authors. A total of 125 terms were identified by the end of this study. These terms are included in Table 1 found in an appendix at the end of the thesis. The development of new terms continued throughout the length of the analysis, and it seems likely that a more extended research project would identify a substantial number of additional terms to describe the tools and data being generated by the community of marine conservationists and ecologists. A comprehensive analysis of all research methods, tools, and data types being used within the aquatic sciences of relevance to conservation is beyond the scope of a thesis project. But the study is still useful, since so little is known about the nature of this domain. The object of this study is to develop a method for beginning this inquiry. This work should serve as a foundation for further investigation within this field.

Special Issues

Volume 26: Special Issue 2

The second special issue featured in *Aquatic Conservation* for the year 2016 drew articles from the 6th World Parks Congress held in 2014 in Sydney, Australia and convened by the International Union for Conservation of Nature (IUCN). The World Parks Congresses are only held once a decade; the event in 2014 drew more than 6000 participants and representatives from over 170 countries attended. The special issue featured 15 articles which focused on policy and public engagement regarding protected areas with particular emphasis put on marine protected areas. Since these articles were not traditional research articles, they were excluded from the statistical analysis in this thesis. However, policy and public engagement are important features of marine conservation and cannot be excluded from the larger domain analysis without losing an important dimension of understanding the scope of the work involved in marine conservation. In the introduction to the special issue Laffoley and colleagues (2016) stated, “In Sydney, meeting the challenges of sustainable development and contributing to community wellbeing were achieved by increasing understanding of the vital role of protected areas in conserving biodiversity and delivering ecosystem services" (p. 5).

Wells and colleagues (2016) offer a history of the development of MPAs and an assessment of current challenges. In the late nineteenth and early twentieth century, inhabitants of many Western nations still subscribed to the notion that the oceans held an inexhaustible supply of fish despite the fact that both indigenous seafarers and Western fishermen had made observations to the contrary. Modest efforts were made within this timeframe to reverse degradation caused by over harvested fishing grounds by temporarily closing fisheries and establishing parks. After WWII awareness of the vulnerability of the marine habitat slowly grew through the efforts of Jacques Cousteau, Rachel Carson, and their successors. A handful of protected areas including the marine environment were established in the 1950s and 1960s. By 1958 the IUCN publicly recognized the importance of establishing protected areas as a tool for conservation. A proposal was made at the Special Symposium on Marine Parkes held in 1966 that a network of Marine Protected Areas (MPAs) be established in the Pacific Ocean, though the proposal was not carried out at the time. A shift in global attitude began to recognize the need to implement MPAs during the 1970s, and in the decades that followed a growing number of studies were conducted and MPAs were established in both developed and developing countries. Despite rapid growth of MPAs in the years leading up to the publication of this article in 2016, protection of the marine environment still lagged behind the international agreement made in 2010 of reaching 10% coverage by 2020. An online search indicated that approximately 5% of the global ocean was included by in MPAs by the target deadline of 2020. Even if the goals for adequate MPA coverage are reached, effective management still poses a problem. As the authors state, "The challenge of effective control mechanisms and governance structures for activities beyond MPA jurisdictional boundaries is deepening with increasing urbanization, industrialization, agricultural intensification and expansion" (p. 118). Meanwhile, experts at the World Parks Congress suggested that a necessary target for achieving sustainable marine conservation goals would be to protect 30% of the global ocean from extractive activities, a target that ocean governance is currently very far from reaching.

Concerns have been raised that if MPAs are established without taking into consideration the impact on the food security of people in developing nations, conservation efforts could constitute an "Ocean Grab." The response to the call for placing 30% of the world ocean under the protection of no-take MPAs has been controversial. While one group of attendees of the World Parks Congress was highly supportive of the goal, another group raised concerns that this goal was unrealistic. Those in opposition felt the goal was, "a frighteningly high 'aspirational' target, the consequence of which in densely populated areas in developing countries, would be very serious in terms of livelihoods loss, social strife and political stability" (Charles et al., 2016, p. 177). Many conservationists accept the need to include local communities into the decision-making process if conservation measures are to be effective and equitable. Human rights need to be considered in negotiations over access to marine resources that impact the social and economic development of impoverished coastal nations. This is part of the process of promoting environmental sustainability that is also economically and socially sustainable. Charles and colleagues acknowledge the need for developing sustainable marine environments and suggest that local coastal communities can be strong advocates for conservation so long as their rights to food security and pursing a livelihood are taken into consideration. They recognized that the establishment of MPAs is part of the strategy for creating sustainable marine environments, but they voice concerns over the prospect that the pursuit of managing the oceans by global conservation targets may overlook the diverse needs of individual communities and habitats.

An article by Colleton and colleagues (2016) explores the potential of using computer games as a tool to enhance the educational experience of young people, generate sympathy for fragile marine habitats, and introduce students to environments they are not able to readily visit themselves. The article focuses on two games Infinite Scuba and Planet3. Infinite Scuba was developed in collaboration with the founder of Mission Blue, Sylvia Earle. The object of this game is to promote Hope Spots, regions for MPA conservation by featuring an immersive game simulation of scuba diving to learn about marine biodiversity. Planet3 attempts to teach gamers about the way the Earth operates as a system. These games were featured at the World Parks Congress.

The goal of the World Parks Congress is to create a path towards environmental sustainability. The first WPC was held in Seattle, Washington in 1962 and has met roughly once a decade since then. The 5th WPC held in Durban, South Africa in 2003 placed more emphasis on the need to establish more protected areas and the importance of protecting the marine habitat. The 6th WPC held in Sydney, Australia in 2014 continued to develop these themes. They also placed an emphasis on youth leadership. Looking to the future, they proposed the "Promise of Sydney." This Promise was composed of "a core vision for the future, a set of innovative approaches to solving some of the world's most elusive challenges, a series of commitments for people, protected areas and the planet, and existing solutions that provide evidence that these innovative approaches are in fact within reach—collectively represent a blueprint for change" (Wenzel et al., 2016, p. 251). The Promise looks to offer our children a legacy in which nature is preserved.

Volume 26: Issue 5

The fifth issue of *Aquatic Conservation* published in 2016 marked the 25th anniversary of the journal. Instead of publishing research articles, members from the journal's editorial board collaborated to write a series of review articles addressing some of the main topics covered by the journal. An editorial opening the issue summarizes the publication activities of the journal. Speaking of marine and freshwater environments the authors state, "Apart from the obvious differences between marine and freshwater habitat characteristics, ecosystem processes and species assemblages, these areas are largely affected by different pressures and impacts, subject to different policies and governed by different legislation" (Boon & Baxter, 2016, p. 810). The special issue offers a comparison and contrast of these different systems, also pointing out common themes that unite aquatic research. The story of the journal is one of growth and inclusivity. Though the largest share of article submissions originate from Europe, there are contributors throughout the world. The journal's editorial board also includes international participation across Europe, North and South America, Australasia, Asia, and Africa. The journal's history documents changing trends in research and conservation policy. The journal highlights the need for society to value nature protection not only for the services nature provides but for nature's intrinsic value.

Tricarico and colleagues (2016) review the complex issue of biological invasions stating, "Increasing travel, trade, and tourism associated with globalization and burgeoning human populations have facilitated the intentional and unintentional movement of species beyond their natural biogeographical barriers, significantly altering ecosystems and the composition of biodiversity" (p. 873). The authors anticipation that climate change will exacerbate the problem of invasive species. The problem of invasive species extends beyond organisms being outside of their native habitats, potentially invasive species outcompete local species creating a greater sense of endangerment to fragile populations, and sometimes non-native species actively change the new habitats that they invade. Data shows that thousands of aquatic species can now be found outside their native ranges. To manage the problems associated with invasive species, data sharing is important. Additionally, "National inventories of established aliens will need to be updated regularly, and public engagement will also be needed, not least to discourage the import and release of non-native species" (p. 886).

Geist and Hawkins (2016) review the subject of restoring aquatic ecosystems comparing marine and freshwater habitats. Writing of marine ecosystems, they observe that greatest restoration potential includes sites with some degree of enclosure such as lagoons. Conversely sites that are open have more potential for natural recovery since organisms from other regions may recolonize degraded habitats. When structuring organisms are lost from a site even in open coastal waters, replacement of these organisms can serve the purposes of restoration. Organisms such as seagrass, mangrove trees, kelp, molluscs, polychaetes, and corals literally reshape their environments. Their loss changes the physical structure of the habitat, which can only be restored by recolonization. Geist and Hawkins characterize marine systems as being more open and having greater connectivity to freshwater systems. Freshwater systems are also impacted more heavily by land use of the terrestrial ecosystems that surround them. While restoration of freshwater systems may require active mitigation, frequently the best strategy for marine restoration involves eliminating the biological pressures that have led to degradation and letting time do its work. Restoration efforts sometimes only restore a pale shadow of the unimpaired system, "Remediation might be the best that can be achieved by intervention. This also implies that conservation of remaining top quality habitats should have greatest priority since restoration is only the second-best option” (p. 956)

Volume 27: Special Issue 1

A supplementary issue of *Aquatic Conservation* was published in September 2017 that included articles published in response to the September 2016 meeting of the World Conservation Congress that was held in Honolulu, Hawai'i. The majority of the supplementary articles published in this issue were not research articles, but instead focused on policy issues. The three research articles included in this issue are included in the statistical analysis and the policy papers are excluded. However, as previously stated, policy does represent an important aspect of the domain of marine conservation. These articles were all read, so a brief summary of this issue could be included within the domain analysis in acknowledgement that policy issues matter to marine conservation. In the forward to this issue, the importance of collaboration "with the public, industry, NGOs, and across international borders" (Armor & Lefebvre: 2017, p. 3) was emphasized. The World Conservation Congress is hosted by the International Union for the Conservation of Nature (IUCN) every four years. According to the IUCN website, this organization is, "a membership Union of government and civil society organisations. Together, we work to advance sustainable development and create a just world that values and conserves nature" (IUCN, accessed September 1, 2022). It brings together over 1400 member organizations from over 160 countries.

The introductory article for the 2016 congress indicates that over 10,000 people from 176 countries attended the conference. Though the IUCN addresses environmental issues beyond the aquatic environment, at the 2016 conference ocean issues were considered to be a top priority.

Members attending the IUCN conference acknowledged the need to reach out to the public, "A major theme continuing from the World Parks Congress was a need to reach out to all audiences to encourage people to connect with and appreciate nature. A lot of these conversations were structured around the pavilions (recyclable made from cardboard!), which offered places for people to gather formally and informally" (Laffoley & Lundin: 2017, p. 4). The IUCN brings together governmental agencies, non-governmental organizations (NGOs), and indigenous groups to negotiate the decision process. Before and during the Congress 121 motions were approved, including 85 which were voted on online before the conference. The Congress affirmed, "commitments for a strong new United Nations agreement on High Seas biodiversity protection and management, while the latter commits to increase the scale of strict protection of marine biodiversity using marine protected areas to 'at least 30%' coverage by 2030" (p. 5). Members of the conference expressed concerns that the environmental impact associated with climate change and other forms of degradation was impacting different areas of the world and varying rates, and the Arctic was one region that was most greatly impacted. They expressed hope that conservation work such as the development of marine protected areas (MPAs) may make a significant difference in obtaining their conservation goals.

The first article from this conference focuses on connectivity between MPAs. Carr and colleagues (2017) define MPAs in the following terms, "An MPA is a regime of rules restricting some or all human activities in a delineated area of the marine environment, designed to protect that area (or some aspects of that area) from the restricted human activities and, thereby, to achieve specified objectives" (p. 7). There are limits to how effective a single MPA can be based on the frequency and range of animal movements. For this reason conservationists have recognized the need to make use of a network of MPAs to achieve their conservation goals.

MPAs frequently strive to conserve biodiversity and ecological phenomena. Movements of individuals and communities can occur on multiple spatial scales, so no one solution can protect the whole environment. Anthropogenic influences can also occur on multiple scales impacting local regions and propagating across more extended environments. MPA networks provide a more effective means of protecting genetic diversity of individual species and communities of organisms than an individual MPA can provide. MPA networks also help provide added protection to organisms that migrate over the course of their life cycles. For MPAs to work effectively it is necessary to strategically consider issues of location, size, shape, proximity to other MPAs, incorporation of multiple habitat types, ocean currents and other oceanographic features, as well as if species and communities that need to be protected are located inside or outside the boundaries of the MPA. It is also critical to include nursery habitats within the confines of MPAs to ensure stocks can be maintained. MPAs should also respond to global environmental changes associated with climate change and other factors. Over time the most critical regions for conservation can shift geographically as physical and biological factors in these dynamic systems alter. "First and foremost, MPAs and MPA networks must be connectivity-informed: designed, used, and managed according to the principles described in the preceding section and to evolving principles for incorporating ecological spatial connectivity" (p. 23).

Analysis of Data Types and Tools

Prior to commencing this domain analysis, a review of current literature failed to reveal any studies that were similar enough to this work to provide a controlled vocabulary for defining data types and tools. For this reason, it became necessary to develop a controlled vocabulary on-the-fly. This process involved reading full-length articles and identifying the kinds of data that the researchers were generating. The majority of the material that was coded was found within the “Methods” sections of the relevant articles. Occasionally, data was not mentioned directly within the methods section, but was later identified while reading the “Results” or “Discussion” sections of the articles. While it quickly became evident that some terms were used frequently, many terms were only used once. Of the 125 terms developed over the course of this research, 53 (42.4%) only appeared one time. At the other extreme the tool identified as “Statistical software” appeared in 194 (69.0%) out of 281 records. In the recording of raw data, multiple instances of statistical software sometimes occurred in the records, since the raw data tracked the different types of software used. However, for the data table (see Table 1 in Appendix 1 at the end of the thesis) only a single instance of the use of statistical software was recorded per record to ensure it would be possible to determine what percentage of the total records clearly made use of some form of statistical software. Another term “Genetic software” was also treated in a similar manner, since studies of population genetics frequently used multiple genetics programs in the process of analyzing their results. It was not uncommon for scientists to use ten or more genetics programs to investigate various aspects of the genetic structure of the organisms studied.

Frequently used terms

The top 11 terms are analyzed first, as these are all terms that account for at least 10.0% of the records in the entire data set. As already stated, the most frequent term was “Statistical software.” Most frequently the statistical software used was based on the R programing language. The second most frequent term was, “Population data (geographic).” This term was used 106 (37.7%) times. Unlike statistical software this represents a type of data being generated by the scientists rather than a tool being used. Six of the top eleven terms were some form of population data, as will be made obvious in the results that follow. Because there were so many types of population data being gathered, it became obvious from the beginning of this research project that this term needed to be further refined into sub-terms to accurately characterize the kind of work being generated by this community. As the "geographic" sub-term indicates, this data addressed the geographical distribution of the population being studied. The third most frequent term "Maps" is closely linked to the second most frequent term "Population data (geographic)." The term is "Maps" appeared 74 (26.3%) times. Not all maps were of population distributions, but they did frequently provide the graphic distribution of this kind of data. The fourth most frequently term was often directly correlated with the third term since it involved the description of the tool that was used to generate maps. That term was "Geographical software" and it appeared 73 (26.0%) times. The most frequent geographic softwares used included various versions of ArcGIS or QGIS.

The fifth most frequent term "Hydrographic data" occurred 46 (16.4%) is distinguished from one sub-term "Hydrographic data (physio-chemical)" which occurs 25 (8.9%) times. It seems likely that, if a more extended research project was performed along the same vein as this one, it would become necessary to develop a longer list of sub-terms relating to hydrographic data. There are many forms of hydrographic data which can refer to processes such as water flow, the temperature and salinity of water, and the chemical properties of water (which was what the sub-term physico-chemical was used to indicate). Because there are so many aspects of hydrographic study it is difficult to determine the best breakdown to create generalizable terms, since when aquatic scientists measure various aspects of the aquatic environment they often measure multiple variables simultaneously. Physico-chemical study of water properties was the most consistent variation. Sometimes the more general term was used in conjunction with the sub-term, but only when other aspects of the water quality were being studied beyond the chemical properties in the same study.

Two terms tied for sixth place: "Photographs" and "Population data (community composition)." Both terms appear 45 (16.0%) times in the records. In the case of community composition studies multiple species of organisms are being considered in the population data. Most of the other terms relating to population data are used in reference to a study of one species or a small number of closely related species. The next four most frequent terms are also related to population data: "Population data (numeric)" occurring 41 (14.6%) times, "Population data (morphometric)" occurring 36 (12.8%) times, "Population data (occurrence of non-natives)" occurring 34 (12.1%) times, and "Population data (genetic)" occurring 30 (10.7%) times. Sub-terms are potentially overlapping and may describe a single dataset. It is important to recognize various aspects of the way conservationists study populations. Numeric population data refers to efforts to quantify a population. This task may be relatively easy for highly visible or immobile populations but for small species, shy species, or species that resemble other organisms, quantifying a population can be quite tricky. In cases like these, sometimes scientists only attempt to gather presence/absence data which is not included in the term "numeric." Morphometric data refers to measurements made regarding the size and shape of an organism. Occurrence of non-natives refers to records of organisms outside their native range. This is often considered within the context of invasive species, species found outside their native range that can be damaging to the invaded habitat or can prey on or outcompete vulnerable native species. In some papers a single invasive species is closely studied, but in other cases, scientists will try to keep records of all relevant non-native species observed in the field.

The tenth and eleventh most frequent terms are closely associated. As previously stated, the term "Population data (genetic)" occurs 30 times. "Genetic software" occurs 29 (10.3%) times and is almost always found in conjunction with the term for genetic population data. Genetic software is a tool that nearly all of the scientists recording the genetic structure of a population recorded using. By the time range this research project examines, 2016-2018, a large range of computer-based genetic analytical tools had been adopted by the community of aquatic conservationists. However, genomic sequencing is a new technology that emerged in the late twentieth century. The development of technology was largely driven by the Human Genome Project. The Human Genome Project ran from 1990-2003. This groundbreaking study has helped lead to the development of the methodologies and the computer applications necessary to study genetic aspects of populations (Collins et al., 2003; Garcia-Sancho et al., 2022). The computer based analytical tools now used by aquatic scientists have only been developed in the past one to two decades. The ethic of data sharing of genomic sequences is largely a product of the Human Genome Project (HGP). In 1998 the HGP adopted the Bermuda Principles for human genome sharing based on a meeting held in Bermuda in 1996. During the project the collaborating agencies adopted a policy of providing daily updates to DNA sequence information to publicly available databases (Jones et al., 2018). One of the databases that the HGP deposited its information in was the NIH repository GenBank. The database had been established in the 1980s as a location for molecular biologists to share their sequence data. Since that time, it has become common practice of scientists studying the genomics of organisms to make this data publicly available in databases such as GenBank.

Based on the data from this survey, it is difficult to assess the importance of GenBank to aquatic biologists. Scientists frequently fail to report exactly how they are using GenBank data as part of their research methodology. Sometimes scientists report contributing DNA sequences to GenBank in their methodology section, but other papers make no direct statement regarding this issue. Frequent references to GenBank in literature reviews and other parts of the scientific papers indicate that aquatic scientists rely heavily on GenBank, but this could not be quantified using an identical methodology to key words developed for the controlled vocabulary for the other terms in this study. It's clear that GenBank has become an invaluable tool within the scientific community, and the importance of this data is only likely to increase as more genetic sequences are recorded over time.

Repeated Terms

Over half of the terms developed in the course of this study were used only one to two times. Because of the smallness of the dataset compared to the large output of articles in marine conservation and ecology, it is too early to determine how important these terms are. A broader study of journals may reveal that some of these tools and data types are used frequently by the community. Further consideration of this material will therefore be reserved for the discussion chapter. This leaves 47 terms that appear 3 (1.1%) times to 25 (8.9%) times within the data set. It would require too much space to discuss each of these terms individually, and the analysis will focus on aggregates of terms that are related to each other.

The largest set of closely related terms has to do with fishery related data. Four terms capture different aspects of fisheries: “Fishing effort” 23 (8.9%) occurrences, “Historic fisheries data” 14 (5.0%) occurrences, “Bycatch” 14 (5.0%) occurrences, and “Fisheries data” 5 (1.8%) occurrences. It should come as no surprise that fisheries related data constitutes an important aspect of marine conservation data. The use of historic fisheries data involves researchers making use of prior fisheries datasets. This demonstrates a trend that is confirmed in the other aggregations that the conservation community frequently recycles data.

The next set of terms examined is not quite as closely related, but most of them constituted geographically related terms. These five terms are: “GPS data” 21 (7.5%) occurrences, “Satellite data” 20 (7.1%) occurrences, “Aerial photographs” 9 (3.2%) occurrences, “Online geographic data” 4 (1.4%), and “Geographic data” 4 (1.4%) occurrences. Considering these terms in conjunction with “Maps” and “Geographical software” it becomes obvious that spatial aspects of data are quite pertinent to conservation. It should be noted that “Online geographic data” and “geographic data” are non-overlapping terms. If it was clear that data could be accessed online, it was defined as being from an online source. The more general term geographic data refers to data that was either clearly stated as being from an offline source or if the description was indeterminate. Satellite data, online geographic data, and geographic data serve as further examples of borrowed data.

The two terms “Online database” 20 (7.1%) occurrences and “Scientific literature” 16 (5.7%) occurrences also constitute borrowed data. In the case of scientific literature researchers borrow various parameters in their investigation from scientific articles. This term was not used within the context of a standard literature review. It was only when these sources of data were directly indicated to be part of the researcher’s methodology that this term was employed.

Continuing the trend of borrowed data, we find another aggregate of three terms: “Historic population data” 19 (6.8%) occurrences, “Historic geographic data” 4 (1.4%) occurrences, and “Museum data (taxonomic)” 3 (1.1%) occurrences. Historic population data, the most frequent of these terms, involves the use of non-fisheries related data characterizing the size and distribution of organisms or communities of interest. Survey data and museum specimens represent invaluable sources of information for trying to reconstruct past populations (Bradley et al., 2014).

Returning to newly generated data types, an important factor of conservation involves understanding species movements or other aspects of their behavior. “Behavioral data” 21 (7.5%) occurrences and “Tagging data” 15 (5.3%) occurrences represent two prevalent types of data recorded in reference to organism behavior. Behavioral data is a broader category than tagging data. In the case of tagging data, scientists will attach or insert a tag within a mobile organism to learn more about their movements. Behavioral data may involve any observation of behavior considered important to understand social interactions, reproductive behavior, or other relevant activities impacting the strategies that must be employed to manage the habitat.

Another important trend for developing conservation strategies is understanding human behavior better. Conservationists have been borrowing methodologies from sociological survey methods to better understand the human component of conservation. This trend can be seen in reference to the following terms: “Sociological surveys (questionnaire)” 15 (5.3%) occurrences, “Sociological surveys (interviews)” 11 (3.9%) occurrences, and “Sociological surveys (semi-structured interviews)” 6 (2.1%) occurrences. Researchers have surveyed both professional and recreational fishermen, scientific experts, residents of developing countries, and indigenous peoples to try to gain better understanding of how people interact with their environments. Knowledge serves as an important factor in communicating the need for conservation and generating understanding among various parties regarding resource use.

This analysis by no means provides an exhaustive explanation of what can be gleaned from the data gathered in the course of this research project, but it does provide an overview of the most important trends at least from a numeric perspective. There are important issues, however, that cannot always easily be defined in numeric terms. This uncovers one of the advantages of the current research method. Reading whole articles to yield quantitative results is a laborious process, and by its nature this procedure limits the scope of the investigation. But the reader also learns significant qualitative information that lends deeper scope to the meaning the statistics. Next, the analysis will turn to a matter that is deeply significant to the community of marine conservations that a simple quantitative analysis of data products used in these articles would not uncover.

IUCN Red List

One of the databases that the marine conservation community has become reliant on in the last few decades is the IUCN Red List. Although many papers refer to the Red List, few authors directly used the Red List as part of their research methodology. Within this study only a handful of articles, five to be exact, directly incorporate the Red List into their research, though many make reference to the Red List in their literature reviews or other parts of their papers. Because this database does so much to define the nature of the work being done by this community, a qualitative analysis of three of the papers that use the Red List in their research methodology will be included here in the thesis.

A paper that does a particularly good job of highlighting the value of the Red List analyzes biodiversity off the Central, Western Coast of Africa. The paper by Polidoro and colleagues (2017) relies on a range of data sources and 34 authors participated in its publication. The authors attempted to determine the threat status of over 1800 species of coastal and pelagic organisms found in the Eastern Central Atlantic Ocean. The paper is the result of a five-year research project that examined the status of marine biodiversity in a region of the world that has not been well studied. The authors made use of IUCN Red List data and a publication series from the Food and Agriculture Organization (FAO) a branch of the United Nations (UN) that described marine fish from the region. This information was mapped using ArcGIS software. According to the authors, "The IUCN Red List protocol for categorization of species extinction risk under the IUCN Red List Categories and Criteria, is the most widely accepted system for classifying extinction risk at the species level. The IUCN Red List process consolidates the most current and highest quality data available and ensures peer-reviewed scientific consensus on the probability of extinction for each species. All marine species assessed for the IUCN Red List follow roughly the same protocol: preliminary data collection, validation and review by experts, assignment of a Red List Category, peer-review of assessments, and publication of assessments (and corresponding datasets) on the IUCN Red List of Threatened Species" (p. 1023). IUCN Red List data can be found at (www.iucnredlist.org).

The paper by Polidoro and colleagues (2017) made heavy use of previously collected data from other scientists and projects. Large scale biodiversity projects such as this one depend heavily on data amassed over generations, and the recycling of data represents a critical strategy for conservationists. The IUCN Red List is more than a data repository. A large group of experts collaborate to assign information regarding species extinction risk and distribution. The list includes eight categories of threat, with the most severe being Extinct (EX) and the least severe being Least Concern (LC). The eighth category does not assign an extinction risk because the available data is not sufficient to provide that information. This category is Data Deficient (DD). The study by Polidoro and colleagues indicated that little sampling effort had been conducted in deep waters for the region of concern, so a component of uncertainty accompanies the knowledge of this region. The biggest threat to organisms in the region studied comes from species targeted by large and small-scale fisheries or species vulnerable to fisheries bycatch. Due to harvesting, fish biomass has declined significantly in recent decades. Coastal development, habitat loss, pollution, invasive species, and collection for trade such as aquarium species and seashells also represent threats to marine species along the African coast. According to the study 15% of the species assessed were data deficient, indicating that more species may be under threat than are currently recognized. Assessments such as these constitute an important step in identifying threats to effectively managing species within the marine environment.

The second paper of interest Dulvy and colleagues (2016) results from a collaborative effort of specialists who met in a workshop in 2012 to assess the conservation status of sawfish. Sawfish are a family of rays with unusual morphology. They have long protruding rostra, a long stiff toothed snout that resembles a saw. In some sawfish the rostrum can be as long as 2.5 meters. This unusual morphology makes the rays particularly vulnerable to fishing mortality because their rostra can easily become entangled in fishing nets. Currently the five species of sawfish are endangered. The 2012 workshop met to map the declining range of sawfish and better understand the threat status of these species as described in the IUCN Red List. The work involved in the workshop was highly collaborative making use of historical records of sawfish, database information, surveys of current knowledge, and data posted on social media. The data included lists of sightings for more than a 200 year time span. In the last century all five species of sawfish have seen range declines between 30 - 81%. The declining geographic distribution of these rays makes their populations increasingly vulnerable to local and global extinction. Sawfish are among the worlds most threatened species of marine fish. Though efforts have been made to protect these rays, implementation of these measures may be lacking.

IUCN Red List data is being used to assess the vulnerability of species and communities of organisms on both global and regional scales. An example of a regional study can be found in the work of Raghavan and colleagues (2016) considering the vulnerability of endemic freshwater species in the Western Ghats, a biodiversity hotspot in India. Endemic species have small native ranges, so if they are locally threatened the probability of complete extinction is much greater. Raghavan and colleagues attempt to assess the efficacy of terrestrial protected areas to help conserve species found in the region of their study. Approximately 5% of India's inland water resources are within protected areas, which means more than half of the species they studied were not located within protected areas. The IUCN Red List data for this region revealed that at least 25% of the species the authors considered were known to have high extinction risks. But the true numbers of threatened species in the region may be considerably higher since one-third of the species considered in the study were data deficient. This raises concerns because data deficient species are often neglected in conservation plans. The authors recognize the need to expand the protection of inland waters and develop more effective management strategies.

Chapter 5: Discussion

Introduction

Systematically reading through 21 issues of the journal *Aquatic Conservation* revealed more about the state of the field than can be easily quantified. While scientific literature has the reputation of being cold and objective, it is clear from reading this literature that the researchers are deeply personally invested in understanding the systems and organisms they are studying and discovering effective strategies to preserve nature in all its varied forms. Conservation is a form of science at the intersection of ecology, sociology, public policy, and environmental science. It speaks to people on an ethical and spiritual level. It is a human science where people are at the core of the problem and offer the only hope of finding a solution. Understanding the domain of marine conservation and how it intersects with marine ecology takes a human intellect with the capacity to understand statistics but also it takes a heart of compassion. This is not just a numbers game; it takes a soul to experience the communal aspect of the field and recognize the whole is larger than the sum of the pieces.

Reading this literature changed how I understand the field on an experiential level. There is a process through which data becomes knowledge. It comes through immersion. I know something that I can't point to individual articles to verify. It has to do with the fact that the conservation community is groping for any means necessary to describe aspects of the systems they are studying, complex species interactions, anthropogenic impacts, environmental interactions, and how to rectify damaged systems. They are working at the cusp of human understanding. Biodiversity is almost too complex an idea for humans to make sense of. The systems that conservationists study are chaotic, making prediction an almost impossible endeavor. There is a quantitative aspect to this search that is revealed in the data analysis performed in this thesis. It has to do with the high frequency of data types that were only recorded once or just a handful of times. This aspect of the data matters, because it shows that the community is experimenting with new techniques and tools to try to quantify issues of the systems they are studying in ways that were either previously inaccessible due to technological limitations of the past or that answer questions that previous scientists did not even recognize needed answering. Low frequency data methods may represent emerging methodologies or questions that are not frequently addressed within the community now.

Scholars can't always recognize which emerging methods will become critical to a field at the early stages of development. The conservation community is still in the process of defining what type of work they even do. Within conservation we can't afford to assume that any of the data is low value. As much as is possible, everything needs to be conserved. This is true of the data, but it is also true of the organisms and the habitats they live in. We don't know what the consequences of absence will be. We don't know what will result from our lack of knowledge. We don't know what will result from the absence of organisms within an ecosystem will be. We are learning to our cost, that when species go missing restoring ecosystems can often be much more difficult than preserving them before that loss occurs. Conservationists are still struggling to determine the most effective means of restoring degraded systems (Campbell et al., 2014; Xu & Liu, 2022).

Environmental DNA (eDNA) is an example of an emerging technology that marine conservationists have pinned great hopes on to help fill in knowledge gaps regarding the diversity of organisms in habitats that are difficult and expensive to survey. The technology and information resources to make effective use of this tool are less than two decades old. As the genomes of more species are sequenced and recorded in GenBank taking environmental samples of DNA becomes increasingly more informative. According to Lacoursière-Roussel and colleagues (2018), "Collecting water samples for eDNA surveys could allow rapid sample collection, reduce the cost associated with data collection/shipping, and is less destructive because it does not require the manipulation of organisms" (p. 7764). Because organisms shed DNA into their environment, it is possible to detect the presence of organisms that are too sparse or too well hidden to be detected visually. Though this technique is not 100% effective, since small populations may not shed enough eDNA to be detected, it does increase the odds of locating cryptic species. Analysis of the literature recorded 6 (2.1%) instances of "Water samples (environmental DNA)." The statistical results suggest that this is a moderately important technique. But the newness of this technology implies that there may be substantial potential for future growth in how much the marine conservation community will come to rely on this survey method. It's difficult to tell how many of the data types that were identified in the survey that had very few instances may one day be very important to work of conservation.

It's also difficult to assess the importance of any given technique based on a survey of a single journal. Journals are self-selective genres. The contents of a given journal attract more submissions with similar content. It would take a broader survey of the literature to detect how representative the trends in submissions of an individual journal are representative of the entire domain. There may be important trends within data generation by the marine conservation community that are not captured within the journal *Aquatic Conservation*. The results of this survey are significant, but they are not comprehensive.

The data types that *Aquatic Conservation* records at high frequency are important trends within marine conservation, but they may not be the only trends that are important for this research. The analysis of the data generated by this journal has clearly confirmed that geographical data, population data, environmental data, genetic data, visual data, and behavioral data are all important for marine conservation. It has also demonstrated the importance of recycled data and the growing importance of online databases. What is important from the perspective of data preservation is the heterogeneity of the data being produced by the community. We need to understand the domain of marine conservation to understand how best to serve the interests of this community by identifying what needs to be preserved. Only when the nature of the data is better understood, can information specialists best identify how this data can best be stored for retrieval by future conservationists. The data comes in a variety of forms, while much of it is alpha numeric, there are other forms of media such as satellite imagery, photographs, videos, acoustic data, water samples, other environmental samples, museum specimens, online tools, maps, and software. This does not exhaust all the possibilities, and new media and specimens are likely to be used or collected by the conservation community as new needs and opportunities arise.

Preserving the Data

Libraries are already well equipped for the preservation of traditional textual and electronic sources such as journals and books. When data is presented in these traditional forms, so long as their preservation is prioritized it is easy to maintain their availability to the scientific community. There are also important resources such as satellite data that are being generated outside the marine conservation community. Museums and zoos also hold valuable resources that shape our understanding of biodiversity (Poo et al., 2022). The use of this data represents a borrowing of data that is important to the community, but its preservation is outside the responsibility of this community. In this discussion, I will focus on a number of resources that are being generated by the community that they need help preserving such as maps, environmental samples, museum specimens, and online tools.

Maps

One of the most important activities for the marine conservation community involves mapping biodiversity. Information specialists will need to support the preservation of maps and mapping tools. However, this effort is dependent on the release of the geographical data supporting published papers. According to Assad and colleagues (2018) less than 1% of ecological data is accessible after publication. The authors advocate the use of geo-based website applications hosted on Open GIS platforms to help facilitate the exchange of spatial data and information. They point to an emerging trend to offer online atlases for coastal regions. These tools will be most effective if they include systematic and comprehensive collections of biodiversity data for the regions they map. Assad and colleagues developed an online atlas displaying biodiversity features, areas of importance for biodiversity conservation, and priority areas for expanding MPA networks for the region of the Indo-Pacific. To enhance accessibility for the public they used online GIS software that could be visualized on standard web browsers. They emphasized providing ease of use and making the data available in standard file types such as pdf, jpeg, and gif. Tools such as these offer the marine conservation community an opportunity to share data, but from the perspective of an information specialist the sustainability of these resources becomes a key issue. What happens when the funding supporting the development of such projects is depleted? Are scientists in a position to continue to curate online mapping resources once a project ends? Without archives where scientists can deposit data for projects that are no longer supported much of this data may be lost. Over time systems and platforms become outdated raising further issues of data migration.

Peterson and Herkül (2017) point out that the majority of marine biodiversity data has been derived from point-wise studies. Consequently, there is a mis-match between the way biodiversity data is collected and the way that organisms are distributed in their natural environments. Species distributions are spatially continuous and while some maps produced by marine ecologists display biodiversity in point data, other scientists attempt to map the spatial continuity of marine communities when they visualize their datasets. Species distribution maps are sometimes augmented using satellite data and aerial images and other forms of environmental data. For future scientists to understand the meaning of maps left by their predecessors, metadata will need to record how the maps were constructed. It is also important to maintain access to the raw data the underpins the maps. The projects being described in these two articles are the independent work of scientists, and it is unclear how much support they have received from information specialists. Currently, scientists have little training in handling metadata issues since information science is rarely emphasized in science curriculums. Should greater collaboration occur between the biological community and information specialists, it will be critical to implement more consistent training in how scientists address metadata issues.

Sampling

Environmental and organism sampling poses a number of problems for data preservation to the marine conservation community. Long-term tend analysis of marine populations and environmental conditions offers the conservation community a valuable tool to understand change over time. To do this work datasets from various sources need to be compiled and integrated. Efforts to perform this work can be seen through projects such as EurOBIS and in the LargeNet project described by Vandepitte and colleagues (2010). In a paper including 59 authors a project is described that involved the integration of 67 datasets of samples taken in European marine waters including records from 1858 to 2008. This kind of work poses challenges based on issues of standardizing data and ensuring quality control. Review of taxonomic data revealed problems associated with misspelling and the use of junior synonyms. Correcting misspellings and synonyms reduced the total number of unique taxonomic terms by over 25%. This kind of work, however, cannot correct for misidentifications of closely related species that were recorded in the field in any reliable way. Historical data will always be limited by the skill of the original collectors and taxonomists. Some errors may be uncovered by future scientists based on retrospective work that updates misapplied taxonomic terms, but field identifications are always subject to some level of error that cannot be verified by future scientists if no voucher specimens are preserved by the community. Nonetheless, "Databases which integrate existing data also form an irreplaceable complement to (newly started) longterm monitoring activities, as they represent the only way to expand these recent time-series with their historical counterparts" (p. 11). Despite the advantages associated with integrating multiple datasets, Vandepitte and colleagues note continued reluctance among scientists to share their data. The authors argue that data sharing increases the value of data through time. They note that the passage of time ensures that each data collection event represents a unique and irreplaceable contribution to the general knowledge of an ecosystem. The hope is expressed within the context of this project that it will continue to encourage to cooperation of researchers. A number of prominent ecology journals have adopted policies to encourage data sharing. Interviews of editors from 10 journals in the field of ecology and evolution revealed that these journals required a portion of the data biologists collected to be deposited in public archives as a requirement for publication (Sholler et al., 2019).

Cooperation is desperately needed in the efforts to inventory aquatic and terrestrial biodiversity. Ecologists still grapple with the question, how many species are there? It is accepted knowledge within the field of taxonomy that taxonomic expertise is decreasing (Mora et al., 2011). Taxonomic history represents a complex socio-political legacy since many early efforts to inventory the world's organisms arose within the context of colonial European expansion. Early efforts of species collection across the globe were frequently sent to European and American museums, meaning that the voucher specimens for taxonomic identification are frequently in the possession of former colonial nations (Wafar et al., 2011). Sampling of marine organisms is lopsided based on issues such as geographic location, habitat type, species complexity, and accessibility. Large regions within the oceans are still unsampled, meaning that biodiversity estimates are still very uncertain. Continued efforts to inventory marine life require a variety of methods for data retention. Past knowledge needs to be integrated with continuing taxonomic efforts, accessibility to taxonomic data needs to be facilitated for collaborative efforts to inventory global biodiversity, geographic distribution of collected organisms needs to be recorded and shared, and there needs to be greater transparency regarding what happens to biological specimens after collection. The data survey conducted for this thesis failed to indicate what happens to biological and environmental samples collected by researchers after they have been analyzed. Since this question does not constitute part of research methodology, it is very frequently overlooked as a pertinent piece of information in research articles. These specimens represent evidence of continuing relevance to the scientific community, since physical samples that are well preserved offer information that transcends the data generated in scientific papers and raw recorded data. As Bell and colleagues (2021) remind the scientific audienc,e natural history collections contain ecosystem data that cannot be obtained from other sources. Sometimes analytical methods for physical specimens are destructive, but when they are not, the question of how they are disposed of or where they are being preserved constitutes an important and often invisible aspect of what information will continue to be to be available to future scientists.

To preserve the data and other resources the marine conservation community will require, the work of information specialists will need to extend beyond physical and digital libraries. Museums are also important sites for preserving information necessary for conservation. Museum collections offer insight into past biodiversity both in the form of historical biodiversity samples and fossil specimens. However, Frisone and colleagues (2018) in a discussion of sponge fossil diversity warn that museum collections can show collection bias as collectors favor rare specimens and fossils with attractive features. A further collection issue that was not stated by the article is that paleontologists often collect specimens that are relevant to their own research and overlook specimens in taxonomic groups outside their research speciality. Museum collections sometimes preserve evidence of extinct species not only in the context of fossil collections, but also historic collections of marine biodiversity can contain species that have not yet been described or have died out since collection.

Documentation of museum collections provide information specialists with a series of problems to be resolved associated with provenance, other aspects of the history of collection, and the development of adequate metadata to adequately describe the collection. In addition, the taxonomic descriptions written by scientists need to be clearly linked to the corresponding specimens held in museums. Scientists, librarians, and museum workers have been working collaboratively to make information about existing collections and taxonomic descriptions more readily accessible online, but the task is daunting and only a fraction of this material is currently available online (Ball-Damerow et al., 2017; Jézéquel et al., 2020). The few articles in *Aquatic Conservation* that directly drew on museum materials in their research methods demonstrated preference for using materials that could be readily searched online. Altogether five articles in the survey drew on museum sources, three (1.1%) provided taxonomic data and two (0.7%) were more generally defined as "Museum data." Two taxonomic articles relied on the records of these specimens rather than the specimens themselves as the data source of interest (Gesundheit & Garcia, 2018; Gonçalves et al., 2018). The third article used type specimens in museum collections to confirm the taxonomic status of five species of rays found in Arabian Seas (di Sciara et al., 2017). Museum specimens can be used to augment collected data in the field as the case of De Castro and colleagues (2016). In this study tissue samples for DNA analysis were extracted from museum collections of dusky dolphin (*Lagenorhynchus obscurus*) to compare with tissue samples collected in the field.

Even something as simple as clearly identifying in which collection a specimen is located poses as significant barrier to access if it is not well documented. Sabaj (2020) recognized the importance of this issue and provided a list of institutional codes for 2064 institutions that have ichthyology and herpetology collections. Not all collections contain taxonomic voucher specimens, but that doesn't mean that the material doesn't include valuable evidence. Plankton samples can contain fish eggs, embryos, and larva and as Browman and Skiftevik (2014) point out, there is still a lot of work to be done to understand the early life history of fish.

Online Resources

The data demands associated with studying biodiversity and other aspects of conservation motivates the continuing production of online tools and other resources. This work generates new needs for online curation that scientists may not be able to meet if their resources are not backed by significant institutional support. Governmental organizations host online resources being used by the marine conservation community, and in cases such as these so long as governments continue to prioritize the curation of these sites their continuity is likely to be maintained. Many conservationists are already familiar with institutional resources from organizations such as the FAO at the UN and NOAA in the United States. Pathak and colleagues (2019) describe a portal for searching fish genomics hosted by the National Agricultural Bioinformatics Grid (NABG) in India. National universities also host various tools and databases used by the marine conservation community. University databases can be used to facilitate education like the kelp forest database hosted by University of California Santa Cruz. Undergraduate and graduate students from a number of institutions have collaborated to provide data entry for this resource that is used for ecosystem modeling (Beas-Luna et al., 2014). Some projects are so large and generate so much data that they require support from multiple institutions. DNA and RNA data from Tara Oceans and Malaspina expeditions record the genetic diversity of plankton samples collected around the globe. The raw data generated from this expedition was so massive that it required computer facilities beyond the means of most users to host it. However, the Ocean Barcode Atlas (OBA) was developed so researchers could access this information using nothing other than internet access and a web browser. The magnitude of this project makes it vulnerable since it required multiple government grants and the collaboration of approximately two dozen institutions to support (Vernette et al., 2021).

Biodiversity data needs to be supported through the accumulation of massive numbers of distribution records. Scientists are concerned that the limitations of their research efforts will prevent adequate distribution records from being created without help from outside the institutions they work for. Scientists hope that distribution records might be augmented by the participation of citizen science. Travelers and local enthusiasts take many pictures of animals, and while these photographs may only be useful for relatively recognizable plants and animals, even this limitation does not prevent scientists from exploring the option of using this data. Volunteer museum workers and ichthyologists in Japan collaborated in creating a website that curates photographs of fish from marine waters along the coast of Japan. Miyazaki and colleagues (2014) document this project and note efforts of similar online photographic databases of fish from Japan. Copyright issues have hampered the utility of these projects since amateur fish photographers retain the rights to these photos.

If the survey of *Aquatic Conservation* is accurate, marine conservationists are more interested in employing citizen science data in theory than in practice. Less than two percent of the research articles surveyed included data derived from citizen science sources. To assess the level of interest in citizen science in this journal a full text search of the term "citizen science" was performed. 100 occurrences were found for the 31 years of publication. Narrowing the search to the years 2016-2018 showed that 18 articles included the term. However only 14 of the articles were full length and included in the 320 articles read from this study. A disproportionate number of these articles were not research articles. Two were review articles and three were supplementary articles that were on policy rather than research. This means that over a third of the articles of the 14 were hypothetical discussions of the possibility of using citizen science rather than practical applications. Of the remaining nine research articles that mention citizen science less than two thirds actually draw data from citizen science sources.

As more data is recorded scientists grapple with making this material accessible. Different efforts at collecting similar types of data are often difficult to integrate. The question of data structure arises as scientists and information specialists attempt to create new platforms, databases, and tools to facilitate use of data. As Moura and colleagues (2021) state, "As data are generated across various fields and multiple researchers, we face the challenge of integrating this information into actionable management strategies, hopefully to outpace the loss of coral cover" (p. 9). For some time, scientists have been aware of the difficulty posed by current data retention practices. In a discussion of the fate of marine mammal tagging data it is stated, "Some data are already stored in public databases, but the vast majority are analyzed once and shelved. Placing them in a publicly accessible database would help biologists who want to develop a more complete picture of ocean ecosystems" (Knight, 2002, p. 4). Scientists are aware of the problems they face in making data accessible, but they are not always sure of the best solutions. There is great need for increased communication between scientists and information specialists to facilitate knowledge of what solutions are currently available to meet these needs.

Limitations

It would be beneficial to perform a more extensive domain analysis than I was able to do in the course of conducting the research for my masters thesis. The fields of marine conservation and marine ecology are extensive, and it is unclear how much overlap exists between them in current practice. The literature generated by conservationists and ecologists is in the realm of big data. The research in these overlapping fields generates massive quantities of biodiversity data, and it also draws on huge data sources of environmental data produced outside the field. However, because the analysis conducted within this domain analysis was unprecedented, it was impossible to effectively employ big data techniques to quantify or describe the kinds of data being generated by the field. If a researcher is unable to identify what they are looking for, they can't use standard search practices to find it. It's not enough to look for what you already know is there if the question is, what do I not know? For this study it was necessary to sacrifice comprehensiveness for thoroughness. As a result a small dataset was analyzed to thoroughly describe the range of data being produced by members of the marine conservation community.

The work of this domain analysis is not sufficient to define the scope of the field or determine where marine conservation overlaps with marine ecology and where there is no overlap. It's unclear that marine conservationists even know the full range of material within marine ecology that will ultimately be useful in understanding how ecosystems work and what can be done to better manage them. The question of overlap is transitory, since we cannot forecast how much information within the field of marine ecology that is currently not being used by marine conservationists will ultimately be shown to be critical to understanding how to conserve marine ecosystems. The complexity of the field of marine ecology hampers adequate knowledge of how to apply the full range of resources within the system to predict best management practices.

It is easier to track one species than a whole community. But the fate of a species is not isolated from the community. While marine conservationists recognize that species interactions impact how species function, the analysis of *Aquatic Conservation* suggests that the conservationists submitting articles to this journal have not yet determined how to incorporate current research into the exploration of this complicated subject. To illustrate this point, I would like to point out the term “Population data (species interactions).” This term occurred 10 times (3.6%) in my analysis. That in itself does not explain why this result appears to be so under representative of the field. What must be pointed out is that each occurrence of species interactions within this data set referred to only one situation. The issue being studied was the relationship of a juvenile parasitic phase of freshwater mussels that infect fish that carry these mussels upstream so they can repopulate the stream. Ten articles addressed this issue because conservationists are gravely concerned that freshwater mussels will go extinct. This cannot be the only instance where species interactions presents a significant challenge to aquatic conservation. Parasitism presents a range of difficulties to conservation, in this case conservationists were only studying a form of parasitism beneficial to conservation goals. But parasites also can gravely threaten the survival of vulnerable species. Parasitism is not the only form of species interaction that has implications for conservation. Beas-Luna and colleagues (2014) pointed out four categories of species interactions: trophic, competitive, facilitative, and parasitic.

In a limited way trophic data is represented in this domain analysis. Terms such as “Dietary data (faecal samples)” 1 occurrence (0.4%), “Food web data (benthic biomass)” 1 occurrence (0.4%), “Food web data (drift biomass)” 1 occurrence (0.4%), and “Stable isotope data (dietary)” 2 occurrences (0.7%) indirectly approach the subject of trophic interactions. But this data does not genuinely represent direct species interactions as the primary target of the study. All four categories of species interactions pointed out by Beas-Luna and colleagues (2014) are relevant to marine conservation. The sparsity of records of studies of species interaction within *Aquatic Conservation* may be an artifact of the time range of this study. The journal has been in production for 31 years and the analysis only covered 3 years of that time range. It may be an artifact of the journal selection, and other conservation journals may be producing a substantially larger range of articles on this subject. Or it may be an indication that conservationists have not yet had the opportunity to explore this subject in depth. Only a study of much broader scope than this one can answer this question.

Trophic relationships can determine the survival of an endangered species. An example from forest conservation shows how critical species interactions of this kind can be for management and conservation. Taylor (2000) points out that a seemly insignificant animal in a forest such as a flying squirrel can turn out to play a keystone role in ensuring the survival of an endangered species. Conservation practice cannot succeed without recognizing how critical keystone species are to maintaining a functioning system. Paine's (1969) work on keystone species showed ecosystems rely on complex trophic relationships. The Northern Spotted Owl relies on flying squirrels for 50% of their diet. Flying squirrels rely on truffles for food. Truffles have diminished due to deforestation. Flying squirrels have diminished due to lack of food. An endangered species such as the Northern Spotted Owl is at risk and can only be restored by the management of truffles and flying squirrels as well as other issues that threaten the owl itself. This illustration applies to relationships within the marine environment, yet no papers on keystone species were found in the analyzed dataset.

A relatively frequent term in the domain analysis "Population data (community composition)" 45 occurrences (16.0%) implies that species interactions matter but fails to record how these species interactions effect the community. Community composition is frequently acknowledged to be impacted by harvesting, but it takes a detailed description of differences between harvested and unharvested areas to uncover species interactions in the process. An article by Ashworth and colleagues (2004) demonstrates how careful analysis of marine communities in fished and unexploited zones can reveal the impact of predation as altered by human activities. In the case of this study they considered no-take zones (NTZ) and fished areas in South Sinai, Egypt that were being used by a small community of Bedouins. Artisanal fishing practices not only removed preferred food species, it further altered the structure of the community by releasing some species from predation pressure by fished species. Sea urchins were more abundant in fished zones because the fish that fed on them were being removed through fishing. Also smaller species of non-commercial molluscs occurred in greater abundance in fished regions because they were released from predation pressure. This paper illustrates that human fishing activity alters species interactions. Recording communities only reveals part of how the system is functioning. Thoughtful studies of altered species interactions in response to unnatural disturbance are required to manage vulnerable systems.

To successfully manage vulnerable species knowing behavioral factors such as dietary preferences can present a challenge to ecologists. Furthermore, fisherman frequently accuse predatory species of competing for fishery resources. Sinisalo and colleagues (2006) evaluated the dietary preferences of Baltic ringed seals in Bothnian Bay. For this study they examined a combination of stable isotopes and parasites found in their digestive tracks to determine what food the seals consumed. Trophic relationships determine how parasites are transmitted from one species to another. A parasite can pass through several organisms during the process of predation traveling up the food chain. In the case of this study the parasites helped the authors determine that individual seals had different dietary preferences. Parasitism reveals much about how an ecosystem is functioning, but this data is also absent from the articles examined in *Aquatic Conservation*. Without knowledge of the full range of species interactions, conservationists will be handicapped when they attempt to manage an ecosystem. This domain analysis fails to reveal how much conservationists actually know about the range of these interactions.

What would it take to more fully define the scope of the field of marine ecology and understand how it overlaps with marine conservation? It would require a much larger study than could be carried out while writing a master's thesis. A rough estimate would be a survey of 10,000 articles drawn from at least 10-12 journals in the overlapping fields. This would exclude a full text analysis of the material. A coarse grained analysis could be performed by a researcher if they restricted their analysis to coding abstracts rather than articles. It wouldn't be possible to extract the full range of data being generated in these articles, since this information is not always found in the abstract. But if a person was more interested in defining the subject areas covered by this field, this could be an effective research strategy. It would help marine ecologists to show how much material in their field needs to be taken into account to more effectively manage marine resources.

A study of this nature could be accomplished while writing a dissertation. However, it would require someone with adequate familiarity with the domain of marine ecology who also had skill at abstract indexing. An experienced indexer with the right domain knowledge would be able to complete a study of this magnitude. Much could be learned from it.

Chapter 6: Conclusion

The purpose of this thesis is to aid librarians and information specialists in recognizing the broad, heterogeneous nature of the data being produced by marine ecologists and conservationists. The work of supporting these scientists will require a large investment of time and material resources to be done effectively. The stakes are very high, as marine ecologists fear that marine ecosystems are dying. The oceans have been compared to the life blood of the planet. If the oceans die, the planet will follow. Marine ecology is a big data field. It not only generates big data, it borrows many big data resources from other fields. Environmental data such as that represented by satellite imagery, hydrographic data, and climate data all underpin the fields of marine ecology and conservation. The best chance conservationists have in acting on this data requires that the data of ecology, conservation, and environmental data be readily accessible.

It would take a large team of librarians and information specialists to support the curation of this data. While a number of institutions are already actively participating in this work, the coverage is uneven. Some resources are being effectively curated, but this is not true of everything. There are resources that have been discarded. Others are stored in obsolete forms of data retrieval. Forgotten documents and monographs are slowly disintegrating (Costello, 2007). The sooner recovery of these forgotten resources can take place, the more data can be found and preserved. But this work can't be done until librarians have a better idea what they need to look for to support the marine conservation community. Priorities are set based on understanding what resources are most critical to the communities that libraries and archives serve (Millar, 2017). However, few librarians are qualified to make the determination of which resources are most important to marine conservationists. This thesis offers a starting point in considering where these priorities lie. It is far from the last word on the subject. This thesis can serve as the starting point of a new conversation.

This thesis is identified as a preliminary survey of the data preservation needs of the marine conservation community, because it can only point the way, not define the path. Much more work needs to be done for the task to be accomplished. The journey is long and has not been mapped out yet. The territory is too vast for one person to map out alone. This is a call to action. Hundreds of years' worth of records need to be identified and preserved. Finding aids need to be created to help conservationists identify what they are looking for. Scientists need to be taught new skills to work with a broad range of library resources and archival material (Adams & Bullard, 2014). Existing resources that have already been curated need to be identified and made more visible to the conservation community.

There is a subject that I intended to cover in this thesis, but I did not have time to address. That is information need and information behavior (Case & Given, 2016). The marine conservation community has a deep unfulfilled information need to address the gaps in their knowledge that currently prevent them from accurately assessing what measures can be taken to help preserve the fragile communities that they are studying. This opens up a new category of fruitful interchange that could occur between the library community and marine conservationists. The information behavior of this community should be analyzed to develop new advice and direction to help guide these scientists to existing information resources. Some information gaps cannot be filled since we are dealing with an imperfect record of the past. But until experienced information specialists team up with the marine conservation community and other relevant institutions, it will be impossible to differentiate the unknown from the unknowable.

This thesis was able to uncover a number of important trends in data generation by the marine conservation community. Major trends matter, but emerging tools and new methods of investigation may also reveal much that needs to be known. Statistics can be used to reveal critical information, but much can be concealed within statistics as well (Cohn & Cope, 2001). In the case of marine conservation, the underdog may play a yet undiscovered role in shaping the survival of a marine community. We can't afford to assume that ecological data is irrelevant simply because we don't know what use it is to us. It's impossible for us to fully identify where new researchers in the information resources of marine ecology and conservation should concentrate their efforts. My instincts say we need to know everything. However, this goal is impossible to achieve. After hundreds of years of taxonomy a large percentage of organisms are still unidentified. The range of possible interactions between species are virtually infinite. Like Currie (2018) I believe if the philosophy of science was reevaluated using the historical sciences our understanding of how science operates would be, "a very different beast" (p. 310). There is epistemic value in surveying what is out there just to see what it is.

In historical sciences, no data point is irrelevant. Everything goes into building the picture of how natural systems operate over time. Each data point is unique unless it is merely an accidental duplication of the same record. As familiar as the map of the globe is to a modern observer, in ecology *terra incognita* still exists. This is more than a metaphor and collaborative mapping projects offer new opportunities to integrated the large undefined regions of the marine systems that determine the functioning of these critical environments (Tian & Chang, 2019). According to historian and biological oceanographer Eric Mills (2012) biological oceanography is still a young science. There is still much to be discovered as recent expeditions have confirmed (Przeslawski & Christenhusz, 2022; Rogers et al., 2012). The recent record of discovery suggests that novel biogeographic provinces are yet to be found (Downie et al., 2021). But human influence can reach to unimaginable depths. When I was a graduate student at Scripps Institution of Oceanography, I learned in a colloquium given by another graduate student that when she performed a genetic analysis on the gut contents of copepods in a deep ocean trench, she found that they had been consuming Angus beef. She hypothesized that a previous vessel had discarded the beef overboard during an earlier voyage. According to a recent editorial on deep-sea exploration human litter is observed on the sea floor as often as one out of every five deep-sea dives to the ocean floor (Przeslawski & Christenhusz, 2022). If humans are altering the food chains of deep ocean trenches, we cannot speak with any sense of assurance that such a thing as a pristine ecosystem still exists on this planet. The question is not if not humans are modifying nature, it is merely how much?

Appendix 1

Knowledge Products	**Frequency**	**Percent**
Archeological data	1	0.4
Audio recording	1	0.4
Bibliographic survey	1	0.4
Biomass data	1	0.4
Climate modeling tool	1	0.4
Coastal monitoring data	1	0.4
Conservation model	1	0.4
Conservation web tool	1	0.4
Data entry software	1	0.4
Dietary data (faecal samples)	1	0.4
Distribution of aquarium trade	1	0.4
Fisheries modeling software	1	0.4
Fisheries observer data	1	0.4
Fishing mortality	1	0.4
Fishing pressure	1	0.4
Food web data (benthic biomass)	1	0.4
Food web data (drift biomass)	1	0.4
Geologic data	1	0.4
Growth model	1	0.4
Haemolymph samples (metabolites)	1	0.4

Historic aquaculture data	1	0.4
Historic habitat data	1	0.4
Historic meteorological data	1	0.4
Historic population stressors	1	0.4
Human behavioral data	1	0.4
Human population density data	1	0.4
Hydro-geomorphological data	1	0.4
Hydrographic data (spatial dataset)	1	0.4
Internet search data	1	0.4
Land use data	1	0.4
Land use history	1	0.4
Mathematical modeling software	1	0.4
Microscopic analysis (protist identification)	1	0.4
Number of diver days	1	0.4
Ocean model	1	0.4
Population data (acoustic survey)	1	0.4
Population data (microhabitat use)	1	0.4
Population data (mortality rate)	1	0.4
Pre and post restoration data	1	0.4
Sediment data (granulometry)	1	0.4
Sediment data (size class)	1	0.4
Sedimentation model	1	0.4
Sociological surveys	1	0.4

Sociological surveys (workshops)	1	0.4
Soil characteristics	1	0.4
Stock assessment	1	0.4
Taxonomic data	1	0.4
Threat status (population)	1	0.4
Tissue samples (environmental contaminants)	1	0.4
US census data (2010)	1	0.4
Visual assessment (contact and damage to coral)	1	0.4
Water quality (fecal indicator bacteria)	1	0.4
Weather station data	1	0.4
Acoustic data	2	0.7
Aerial images	2	0.7
Disease detection	2	0.7
Field notes	2	0.7
Habitat classification	2	0.7
Historic hydrographic data	2	0.7
Meteorological data	2	0.7
Museum data (taxonomic)	2	0.7
Population data (growth rate)	2	0.7
Sociological surveys (focus groups)	2	0.7
Stable isotope data (dietary)	2	0.7
Stable isotope data (tissue samples)	2	0.7
Tidal data	2	0.7

Benthic survey	3	1.1
Climate modeling software	3	1.1
Genetic data	3	1.1
Microphotographs	3	1.1
Museum data	3	1.1
Population data (taxonomic)	3	1.1
Sediment data	3	1.1
Sonar data	3	1.1
Anthropogenic data	4	1.4
Climate model data	4	1.4
Coral cover	4	1.4
Geographic data	4	1.4
Historic geographic data	4	1.4
Online geographic data	4	1.4
Sediment data (chemistry)	4	1.4
Ship traffic data	4	1.4
Climate data	5	1.8
Fisheries data	5	1.8
Sociological surveys (semi-structured interviews)	6	2.1
Water samples (environmental DNA)	6	2.1
Population data (demographic)	7	2.5
Field survey data	8	2.8
Sediment data (particle size)	8	2.8

Aerial photographs	9	3.2
Population data (species interactions)	10	3.6
Bathymetric data	11	3.9
Population data (size class)	11	3.9
Sociological surveys (interviews)	11	3.9
Vegetation cover	12	4.3
Population data (reproductive)	13	4.6
Bycatch data	14	5.0
Historic fisheries data	14	5.0
Habitat characteristics	15	5.3
Sociological surveys (questionnaire)	15	5.3
Tagging data	15	5.3
Scientific literature	16	5.7
Video	17	6.0
Ecosystem modeling software	19	6.8
Historic population data	19	6.8
Visual survey	19	6.8
Online database	20	7.1
Satellite data	20	7.1
Behavioral data	21	7.5
GPS data	21	7.5
Fishing effort	23	8.2
Experimental data	25	8.9

Hydrographic data (physico-chemical)	25	8.9
Genetic software	29	10.3
Population data (genetic)	30	10.7
Population data (occurrence of non-natives)	34	12.1
Population data (morphometric)	36	12.8
Population data (numeric)	41	14.6
Photographs	45	16.0
Population data (community composition)	45	16.0
Hydrographic data	46	16.4
Geographical software	73	26.0
Maps	74	26.3
Population data (geographic)	106	37.7
Statistical software	194	69.0

Table 1: Summary statistics from the list of knowledge products from raw data set. These terms were developed in the process of analyzing the knowledge products of the papers from *Aquatic Conservation*. A total of 281 research articles were read and a tally was kept of all knowledge products from the methodology section and other parts of the paper that were actively used as part of the research described in the paper. Knowledge products were recorded as part of a controlled vocabulary developed in the process of research.

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