Marine Historical Ecology in Conservation

Applying the Past to Manage for the Future

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Foreword by Daniel Pauly

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FOREWORD

Marine Historical Ecology in Conservation, the title of this book, may be hard on potential readers, in that each of its two nouns and two adjectives can be seen as potential challenges:

- “Ecology,” because some find it difficult to distinguish the scientific discipline of ecology from the passion of environmentalism;
- “Historical,” because until recently, many academic ecologists suffering from physics envy were attempting to ban history and contingency from ecology;
- “Marine,” because we are air-breathing, terrestrial animals with a strong bias against the watery world that covers most of the surface of our ill-named planet; and finally,
- “Conservation,” because the word implies, for still too many, a departure from what scientists are supposed to do (describe our world, as opposed to changing it, or in this case, developing the tools to prevent it from being dismantled).

Why do we need marine historical ecology and conservation? The fact is that since Darwin’s *On the Origin of Species,* we have become quite good at inferring what existed—in terms of animals and plants—if only because we have (a) fossils and (b) a powerful theory which allows, nay demands, that we interpolate between the forms we know existed, because we have fossils, and the forms for which we have no direct evidence but which we can link to present forms, including us humans.

Thus, in a sense, we know most of what *was there* since the Cambrian, and this knowledge becomes more precise and accurate the closer we come to the present. However, we don’t know *how much* of what was there actually was there, and this may be seen as the defining feature of historical ecology and its potential use in marine conservation.

One way to view this is that while evolution’s “central casting” provides us with a reliable stable of actors (e.g., a wide range of dinosaurs in the Triassic or a flurry of mammals in the

Pleistocene), it is for historical ecology to give them roles to play. (Note that these examples imply that historical ecology should mean the ecology of past systems and not only past ecology as recoverable through written documents, as one could assume when relying on a narrow interpretation of the word "history".)

Thus, an ecosystem with, say, sea turtles in it will function in a radically different way if these turtles are very abundant (as they appear to have been, e.g., in the pre-Columbian Caribbean) than it will where sea turtles are marginal, as is now the case in the Caribbean.

The Earth's ecosystems have all been modified by human activities, and this applies also to essentially all marine ecosystems, which whaling and hunting of other marine mammals, and later fishing, have reduced to shadows of their former selves in terms of the larger organisms they now support and the benefits they can provide us.

Some of these ecosystem modifications were unavoidable, as humans living on coastlines are largely incompatible with large populations of, say, sturgeons, sea turtles, or pinnipeds, and our appetite for fish implies that some fish populations will have to be reduced by fishing. But to a large extent, the depredations that we have imposed on the oceans have been entirely gratuitous: we need not have eradicated the great auk (*Pinguinus impennis*) or the Caribbean monk seal (*Monachus tropicalis*) to satisfy our seafood requirements, and thus it is perfectly reasonable to ask ourselves how we could prevent such catastrophes in the future (each species loss is a catastrophe) and whether we can rebuild now depleted populations of marine organisms so as to reduce the risk of this occurring again, and to have more to enjoy.

This is what marine historical ecology in conservation is for: to inform us about what these populations have been in the past, and under which conditions these populations could flourish so that we can start helping them do so. This is what the neat book you have in your hands is about.

Daniel Pauly
Vancouver
August 2013

FOUR

Using Disparate Datasets to Reconstruct Historical Baselines of Animal Populations

FRANCESCO FERRETTI, LARRY B. CROWDER, and FIORENZA MICHELI

When reconstructing long-term changes in marine ecosystems and populations of marine animals, historical data are needed to encompass the natural scale of population dynamics, disentangle short-term variability from longer fluctuations, and describe events that occurred decades or centuries ago. Historical data, however, are often difficult to obtain, vary greatly in format and quality, and were less consistently collected than most modern quantitative data. Concern for incorrectly integrating such different sources of information across long periods means that many historical datasets are used only in part or not at all. However, for many locations, such datasets provide the only sources of information on changes to populations or ecosystems. In this chapter, we review methods for accessing and incorporating disparate forms of historical data into quantitative historical reconstructions for marine species. We show how reconstructing historical baselines and documenting long-term changes can provide a powerful means to engage the public and motivate and inform policy reform. Our examples include Mediterranean fisheries and historical analyses of sharks and rays, a region and species group characterized by long histories of exploitation.

INTRODUCTION

Historical baselines of species abundance and ecosystem structure are often unknown because of limited human observations and a paucity of records, with those records that do exist often extending back only several decades (Bonebrake et al. 2010). Especially in the ocean, where ecological processes are generally concealed from direct observation, there is a continuous intergenerational loss of information on the “natural” structure of marine ecosystems (Pauly 1995, Pauly et al. 2005). For large marine animals (e.g., sharks, pinnipeds, seabirds, cetaceans, marine turtles), the effect of this information loss can be particularly severe because these species are long lived, slow to reproduce, and highly migratory (Musick 1999, Pulliam 2000, Collie et al. 2004). Our scientific understanding of the ecological processes that occur across these spatial and temporal scales is still fragmentary (e.g., Myers and Worm 2003, Myers et al. 2007, Block et al. 2011).

For these reasons, describing long-term population trends and ecological processes for large marine vertebrates is difficult, and approaches using multiple sources of historical information are increasingly being used (Myers and Worm 2003, Myers et al. 2007, Baum and Worm 2009). This chapter uses real-world examples to review the technical and analytical challenges of using disparate historical datasets for assessing long-term changes in marine species and ecosystems. We outline analytical methods and case studies that show the utility of integrating multiple heterogeneous datasets to estimate baselines of population abundance and ecosystem structure. Historical data provide great challenges and opportunities for reconstructing long-term baselines of animal populations. We show that virtually any form of data can be incorporated into quantitative assessments, given certain caveats, and that such integration can provide important guidance for marine management, conservation, and understanding of ecological processes. We draw primarily on examples related to long-lived species such as elasmobranchs (sharks and rays), showing that vulnerable marine animals can be amenable to approaches that reveal historical population changes. The overarching goal of this chapter is to explore the challenges and possibilities of using multiple datasets and data-gathering techniques to generate such trends and infer ecosystem change, and to illustrate the utility of these long-term historical analyses for motivating and informing policy changes.

CHALLENGES AND OPPORTUNITIES OF A HISTORICAL ECOLOGICAL APPROACH

Comparing Apples and Oranges

Historical data vary greatly in scale, nature, and quality. Technological advances and development in study design and analytical capability have allowed for the gathering of progressively more detailed and complex marine data that differ even from those collected a few decades ago. A widespread approach to dealing with information of varying quality is to select the data with the highest quality and consistency of collection and disregard the rest (McClenachan et al. 2012). Thus, many researchers discard potentially useful datasets to avoid comparing "apples and oranges." For example, when evaluating the status of exploited commercial fishery resources, the Scientific, Technical and Economic Committee for Fisheries of the European Commission often uses only high-resolution survey data (Anonymous 2007). This is the case even when historical information from similar monitoring programs exists (see the discussion on combining heterogeneous data below, under "Sharing and Accessing Data"). While comparisons across datasets should be made carefully, completely discarding information is rarely appropriate in historical studies of marine systems, where data are difficult and expensive to collect. Possible consequences of ignoring available information include poor fisheries management, flawed extinction-risk assessments, and, consequently, inadequate conservation planning (McClenachan et al. 2012; also see chapter 10, this volume). Learning how to use every bit of relevant and available information can produce more robust assessments of current population and ecosystem status and, therefore, better management and conservation plans.

Fomenting a Philosophical Shift

It is generally accepted that historical data can be used qualitatively to contextualize more recent quantitative information (Wolff 2000, Sandin et al. 2008). In practice, authors of ecological papers often cite historical sources in describing baseline conditions of altered ecosystems. For example, Sandin et al. (2008) described historical shark abundance in the Line Islands by quoting eighteenth-century explorers: "On every side of us swam Sharks innumerable, & so voracious that they bit our oars & rudder. . . ." Such qualitative uses of historical data have proved useful to contextualize recent quantitative information but can sometimes produce subjective and ambiguous representations of past conditions.

Conversely, analyses that more formally attempt to incorporate multiple and heterogeneous datasets (e.g., quantitative and qualitative data, continuous and discontinuous data series) are frequently criticized for a lack of precision, for inappropriate comparisons, or for making erroneous inferences from possibly spurious correlations (Burgess et al. 2005, Hampton et al. 2005, Polacheck 2006). As we show in this chapter, when data, analyses, and assumptions are properly defined and clearly presented, integrating heterogeneous datasets can provide new insights and a wide range of opportunities for characterizing baselines of historically depleted species and affected ecosystems. Below, we discuss potential benefits of integrative approaches that draw on a broad range of historical data and present examples of the novel insights derived by these analyses.

Data Are Multifaceted

Data often contain multiple bits of information that can be extracted and analyzed in various ways. For example, written records of species behavior, diet, and taxonomy can also be used to identify the extent of occurrence. Fishes sampled for stomach-content analyses also represent occurrence records of species in a particular time and location, and of the food items found in their stomachs. Link (2004) characterized long-term changes in abundance and distribution of benthic invertebrates in the northeast U.S. continental shelf by using stomach-content data published between 1970 and 2001. Temporal trajectories extracted for several groups of invertebrates were congruent with their vulnerability to fishing perturbations and similar to results of meta-analyses on the effect of trawling on benthic habitats (Link 2004).

Translating qualitative information (e.g., on presence–absence, habitat suitability, range distribution, and even temporal trends in abundance) into quantitative metrics of ecosystem and population status is a practice increasingly used to incorporate historical data into large-scale, long-term baseline research (Pandolfi et al. 2003, Lotze et al. 2006, Kittinger et al. 2013). One of the common criticisms of such research syntheses is that the generated indices of abundance may be biased by the subjective perceptions of the researchers who are interpreting historical data (Beyth-Marom 1982, McBride and Burgman 2012). However, Al-Abdulrazzak et al. (2012) found general agreement among multiple individuals in their rankings of anecdotal terms of abundance, showing that irrespective of different individuals' characteristics (e.g., age and ethnicity), people tend to interpret historical information similarly.

This problem can also be addressed by calibrating qualitative data with contemporary quantitative information. With the objective of converting two centuries (1800–2000) of qualitative indices of fish species abundance in the northern Adriatic Sea, Fortibuoni et al. (2010) extracted time series of perceived abundance (very rare, rare, common, very common, etc.) from historical publications up to 1950 and compared them to a time series of landings from a major fish market in the same region. These time series were used to construct frequency distributions of qualitative and quantitative abundances, calibrate the qualitative indices to the quantitative ones, and then produce quantitative abundance estimates for the categorical classes (perceived abundance; Fortibuoni et al. 2010). The authors were thus able to hindcast the quantitative indices of species abundance to periods not covered by the fish landings data and analyze long-term temporal variation in focal species and catch composition.

Creating Order out of Scattered Data

Identifying, combining, and quantifying historical data to understand ecological change requires an approach spanning multiple spheres of knowledge (Figure 4.1). As applied to ecology, this process can benefit from information technology science to gather and organize data, mathematics and statistics to identify the right tools for analysis, and history to understand and interpret data. The diverse skills and perspectives needed to obtain, analyze, and interpret historical data call for interdisciplinary training and collaboration.

In many cases, data are not scarce but are merely scattered, poorly described, or not organized in readily accessible archives. The Mediterranean Sea, for example, has been traditionally regarded as deficient in fishery statistics, and lack of management for many exploited marine species was often excused on these grounds. Yet this region has one of the highest densities of research facilities in the world and, consequently, one of the highest intensities of scientific monitoring (Coll et al. 2010), arguably the longest exploitation history (Roberts 2007), and the longest history of marine observation (Aristotle 350 BC). Thus, a considerable amount of historical information is dispersed in local publications and in institutional and personal archives (Ferretti et al. 2005, 2008, 2013). Such bodies of written records should be preserved, catalogued, and eventually converted to electronic records to avoid temporal degradation and loss of information (Michener 2006, Ray 2009). Describing, cataloguing, and making data accessible once published is increasingly encouraged and

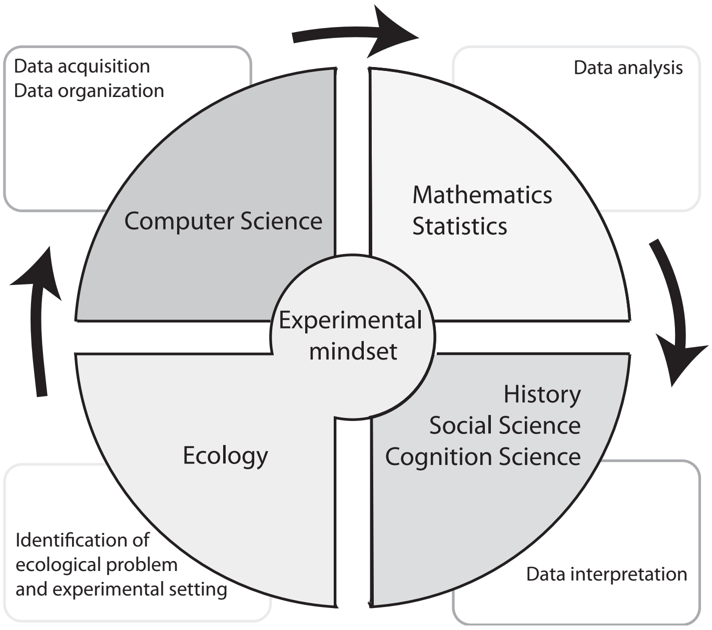

FIGURE 4.1 Schematic representation of the ideal analytic approach to problems of historical data integration. Pie slices represent the different disciplines that can contribute to the process of data integration and analysis. Corresponding boxes are the activities to which the disciplines can efficiently contribute, but contributions are not strictly limited to these. In an ideal historical and integrative analytical exercise, the analyst begins with the identification of the ecological problem and the identification of the system. Then s/he searches for the data and analytical tools required for addressing such a problem. Computer science is instrumental for extracting data from unstructured information and collating and organizing multiple datasets. Mathematics and statistics can help in extracting new information from data and drawing inferences from this information. History, social science, cognition science, and other nonecological disciplines can be useful in interpretation of results, but also in data identification and collection.

rewarded (Michener 2006, Reichman et al. 2011). Producing an inventory of available data and published information (Evans and Foster 2011) allows data tracking, improves understanding of data history and caveats, and facilitates combining data in research syntheses such as meta-analyses (Hafley and Lewis 1963).

Sharing and Accessing Data

In many cases, large datasets are unavailable to the scientific community despite urgent conservation and management needs. The governments of the United Kingdom, European Union, and United States are working toward mandating that all publicly funded research be published in open-access journals (Noorden 2012, 2013). However, this perspective frequently meets strong opposition from institutions when it pertains to raw data. Examples of datasets relevant for historical analyses but not publicly available include data on distribution, abundance, and population demographics of fish and invertebrates sampled by national and international trawl surveys in the Mediterranean (Relini 1998, Anonymous 2007); and European Commission data on fishing effort (e.g., real-time vessel monitoring system data on location, course, and speed of fishing boats) in European waters.

In some cases, data may be accessed through formal agreements with the institutions mandated to perform the sampling operations. In other cases, the process can be tortuous and less transparent and requires an investment of time and research money to sort through the intricacies of policies regulating access to information. For example, researchers seeking access to trawl-survey data to assess long-term changes to populations of sharks and rays in the Adriatic Sea were required to resort to the Aarhus Convention, an international agreement regulating access to publicly funded environmental data (Rodenhoff 2002, Ferretti et al. 2013). Hampering data access in practice shields useful information from a potentially huge creative analytical capacity represented by the international scientific community, which might be capable of tackling the issues that the collecting agencies are mandated to resolve.

A similar problem exists for heterogeneous datasets, which many managers or researchers holding key decision-making positions do not believe can or should be integrated, and data are therefore not made accessible. The case of trawl surveys in the Mediterranean is emblematic. GRUND (National Group for Demersal Resource Evaluation) is a publicly funded scientific trawl-survey program developed to evaluate the status of demersal marine animals in Italian territorial waters (Relini 1998). As part of this program, data on the biology, distribution, and abundance of many commercial and incidentally caught marine species (i.e., bycatch) were systematically collected between 1985 and 2002. Over time, several changes were made to survey design and sampling gear; consequently, the data were often not directly comparable among and within survey sectors. Thirty years after the trawl surveys were initiated, the collected raw data are still not organized into a single database and are not available to the public. Yet they represent the only source of information for many noncommercial species for which fishery-dependent data are unavailable (e.g., many species of sharks and rays). This lack of information caused by the lack of availability of unique—albeit problematic—datasets provides barriers to researchers seeking to use this information to inform management. Making these and similar datasets broadly available for integration and analysis is crucial, and cultural shifts in how this type of data is viewed and utilized are urgently needed.

Extracting Data: Learning from Other Disciplines

Ecoinformatics

Creating data from information and combining disparate datasets benefit from technical capabilities that are often beyond the conventional sphere of ecological training (Michener and Jones 2012). Ecoinformatics and the similar field of bioinformatics are the study of ecological information structure and resulting development of computer technology for its management and analysis. Ecoinformatics is emerging as an important field in ecology as expertise in computer science is needed for mining, manipulating, and visualizing the growing amount of data available through digital publications, websites, online databases, and social networks. The Internet stores a vast amount of information, historical and otherwise, from which it is not always trivial to extract data of interest. It is speculated that ≥80% of the information online is contained in free-form text (Grimes 2008). To be analyzable, this information must be identified and converted to datasets.

Literature analysis employs computational linguistics and statistics to mine the growing body of text available online. Databases can be built automatically through the use of software that extracts the data of interest from structured web pages. The software package rfishbase (an extension for the R programming environment), for example, accesses the FishBase database (www.fishbase.org) through its web pages and encapsulates data in a form that can be readily used for analyses (Boettiger et al. 2012). Text data mining is particularly promising for historical ecological research now that a large body of historical literature is being digitized and made available by academic libraries and Internet-related services (Crane 2006). Notable is the Google Book Library Project, which in April 2013 comprised 30 million digitized volumes (Darnton 2013). Books dating to the sixteenth or seventeenth century, traditionally very hard to access and consult (e.g., Rondelet 1554, Aldrovandi 1613), are now available in searchable format online. Finally, the availability of translation software is also facilitating the access to online literature previously obstructed by linguistic barriers (Crane 2006).

Social Science

Interview surveys are a means of capturing historical ecological information where observations of marine ecosystems or fisheries were not recorded (Johannes et al. 2000, Shackeroff et al. 2011). Interviewing resource users can be a valuable way of gathering historical information about spawning grounds, seasonal migrations, patterns of fishing for many exploited stocks, and other aspects of biology relevant to fishery management (Neis et al. 1999). However, planning and evaluating interview studies is an interdisciplinary process that requires expertise from social science, economics, statistics, and biology (Neis and Felt 2000, Drew 2005). For example, recollection uncertainty and cultural and cognition biases must be taken into account when planning interviews and analyzing their results (Neis and Felt 2000, Daw 2010), and aspects of memory with the least associated uncertainty (i.e., some events are more memorable than others) can be exploited. Saenz-Arroyo et al. (2005), for example, asked 108 fishermen from 11 fishing communities in Baja California, Mexico, simple questions about very memorable moments of their fishing career in relation to their target species, the Gulf grouper (*Mycteroperca jordani*). Questions included: How many fish did you catch on your best day ever? What was the size of the largest fish you ever caught? In what year were these catches made? By posing these questions to subjects in different age classes, they reconstructed a trajectory of change in maximum size and maximum catch of this species from the 1940s to the present day. In general, this process of eliciting information from resource users or experts can be structured so that the resulting data can be applied to particular analyses (Kuhnert et al. 2010). For example, estimates of recollection or expert-opinion uncertainty can be used to build informative priors for Bayesian analytical approaches and then incorporated into more formal stock assessments (more on Bayesian analysis below; Mäntyniemi et al. 2013).

Interpreting Historical Data

Once extracted and organized, data have to be interpreted. Marine historical ecology borrows approaches and expertise from historians, psychologists, archaeologists, and cognitive scientists for interpreting pieces of biological information. Sawfishes (*Pristis* spp.) provide an illustrative case. In the Mediterranean, there is an animated debate on whether locally reproducing sawfish populations have ever existed in the region, in part because the region is considered seasonally too cold to host stable populations (Ferretti 2014). In the absence of any direct physical evidence of these fishes having occurred there (e.g., via museum collections; cf. Box 4.1), Ferretti (2014) conducted an extensive historical search and used a collection of historical publications spanning from 350 BC to the present time to document sawfish occurrence and eventual extinction from the region.

A major challenge in this study was the interpretation of historical records coming from the classical and medieval periods. Aristotle, Pliny, and Oppian described the sawfish in their contemporary treatises of natural history (Aristotle 350 BC, Diaper and Jones 1722, Bostock and Riley 1855), though their quantitative, taxonomic, and geographic detail was vague or absent. The authors' historical context, their biographies, and the aims of their publications suggest that most of their natural descriptions referred to the Mediterranean Sea (Diaper and Jones 1722, Romero 2012). Yet these authors were also exposed to knowledge and information coming from other known ocean basins such as the Red Sea and Indian Ocean. Similarly, in the Middle Ages, sawfish were consistently included in bestiaries produced across Europe and the Mediterranean. However, extracting relevant zoological information from these descriptions is nearly impossible, because in most cases the animals described are mythological and religious allegories (White 2002). Working with experts who have a thorough understanding of how human knowledge is handed down, interpreted, and influenced by culture and religious faith (White 2002) is essential for selecting zoologically relevant facts from a literature that otherwise is obscure to an ecological readership.

Combining Data

Selecting an Analytical Approach

Combining disparate datasets requires identifying the information they contain, understanding their limitations, and implementing approaches for integrating data of diverse type and quality. Every piece of information has a certain degree of credibility, quality, and level of detail. This makes integrative analysis inferential in nature and dependent on a solid base of probability and statistical theory. To combine independent pieces of information appropriately, their individual uncertainty has to be taken into account and propagated. As Ben Halpern relates in his discussion of the Ocean Health Index (Box 4.2), integrative analyses cannot be based on the ideal of a study designed around one's research question and a

BOX 4.1 Viewpoint from a Practitioner: The Role of Natural History Collections in the Field of Historical Ecology

Louise K. Blight

In 2013, researchers at the Smithsonian National Museum of Natural History confirmed the discovery of a new raccoon-like mammal they called the "olinguito" (pronounced "oh-lin-GEE-toh"), the first new carnivore discovered in the Americas in nearly four decades (Stromberg 2013). For biologists and lovers of natural history, it is always exciting to hear about the discovery of a new species of animal, but such events grow increasingly rare as fewer places on our planet remain to be explored. The existence of the olinguito, however, was suspected not because some intrepid twenty-first-century scientist scoured the treetops of the Andean cloud forests with a remotely operated drone, but because a researcher opened a drawer of poorly described specimens at the Field Museum in Chicago.

While extensive use has been made of archived written records in uncovering past and present states of animal populations—as described by Francesco Ferretti and colleagues in this chapter—researchers in the field of marine historical ecology may also make use of the more traditional items found in museum collections. Skins, bones, and even whole animals have long been collected by the Western naturalists and biologists who traveled the world and returned with mementos of the natural wonders found on their journeys. And like the written descriptions of early natural riches (McClenachan et al. 2012), these physical remnants have hidden tales to tell.

Sophisticated modern techniques such as stable isotope analysis (e.g., Schell 2000; also see Box 3.1 in chapter 3, this volume) and DNA tests provide the tools to decipher these stories, as do simpler, more old-fashioned physical measurements. For my PhD research, I searched museum collections from across Canada, the United States, and the United Kingdom, looking for clues about what might be causing long-term population declines in the glaucous-winged gull (*Larus glaucescens*), a common and widespread species of the Pacific coast of North America. Rather than written records, I was seeking gull eggs and study skins (the preserved skin and feathers of a bird), which had been widely collected by early naturalists. I located hundreds of specimens carefully stowed in museums at Cambridge University, the Smithsonian Institution, and elsewhere, and compared them with data collected at my field site in 2008 and 2009. Both eggs and feathers told a detailed tale of changes to local environments over time: stable isotope analysis of feathers indicated that gull diet has changed over the past 150 years, with birds eating less fish over time after the advent of commercial fishing (Blight 2012). More interestingly, I also found that gulls now lay smaller eggs than they did 100 years ago and that they are laying fewer of them (Blight 2011). Overall, these results point to stressed seabird populations and an ecosystem that is likely less productive than it was before Europeans began their commercial extraction of marine resources.

Written museum records and old articles also featured in this research. These provided complementary information showing seabird nesting colonies were eradicated by egg harvesters in the late 1800s. However, the most surprising discoveries, that gull populations of the past had different diet and reproductive output, were derived from the physical remnants of the long-ago ancestors of the birds we presently see along the coast. It has become commonplace to dismiss museum collections as artifacts of a bygone era (Winker 2005), but the emergence of novel applications to new historical ecology questions shows that they represent a valuable resource for this field, with many stories left to tell.

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BOX 4.2 Viewpoint from a Practitioner: Drawing Management Insights from Disparate Data

Ben Halpern

Gaps in data, information, and understanding will always be a vexing problem for science and conservation, whether one is trying to piece together historical patterns and abundances of species, as described in this chapter, or trying to describe and manage ecosystems. All of the challenges, opportunities, and methods the authors describe are equally relevant for efforts to assess and protect the complex social–ecological systems that exist today.

Two messages from this chapter resonate particularly strongly with me, given the type of research I do: the challenges and opportunities that exist when combining disparate data sources, and the urgency to capture and make available any and all data. The world is replete with data—in historical texts, data servers, and people's personal collections—and we risk making poorly informed decisions and potentially losing that information if we neglect to compile and synthesize it all.

Over the past decade, I have focused my work on pulling together data about how humans interact with, influence, and benefit from marine ecosystems, from regional to global scales (e.g., Halpern et al. 2008, 2009, 2012). Doing this work has required an inclusive approach to the data types and sources used in the analyses, innovative solutions to filling key gaps, and substantial efforts tracking down and synthesizing disparate data sources.

A recent example of this kind of work is the Ocean Health Index (Halpern et al. 2012), which synthesizes qualitative and quantitative data from current and past sources across ecological, social, institutional, and economic domains to produce a single assessment of the health of the ocean. Compiling all these data, and then making them freely available, serves as a great resource for scientists and managers, while combining them into a single index allows one to understand the "whole picture" in a way that is nearly impossible from just looking at the individual data layers.

Modern-day management can learn a huge amount from data reconstruction and synthesis efforts such as the ones described by these authors, even if the historical information lacks precision. By assessing what once existed, we can gain insight into what could be. Put another way, our path forward benefits from understanding where we came from. For example, imagine setting fisheries stock-rebuilding targets, species recovery plans, or habitat restoration goals based only on current abundance information. In all these cases, we need to know past abundances and extents of stocks, species, and habitats in order to set appropriate future targets.

The relevance of this chapter to current ecosystem assessment efforts highlights the broader utility of the work described here, while also reinforcing the validity of, and need for, efforts to reconstruct past ecological patterns and processes. The bottom line is that managers must make decisions in spite of missing data. The more that science can inform those decisions, even if the science is only able to paint broad-brushstroke pictures of how things were (or are), the better those decisions will be.

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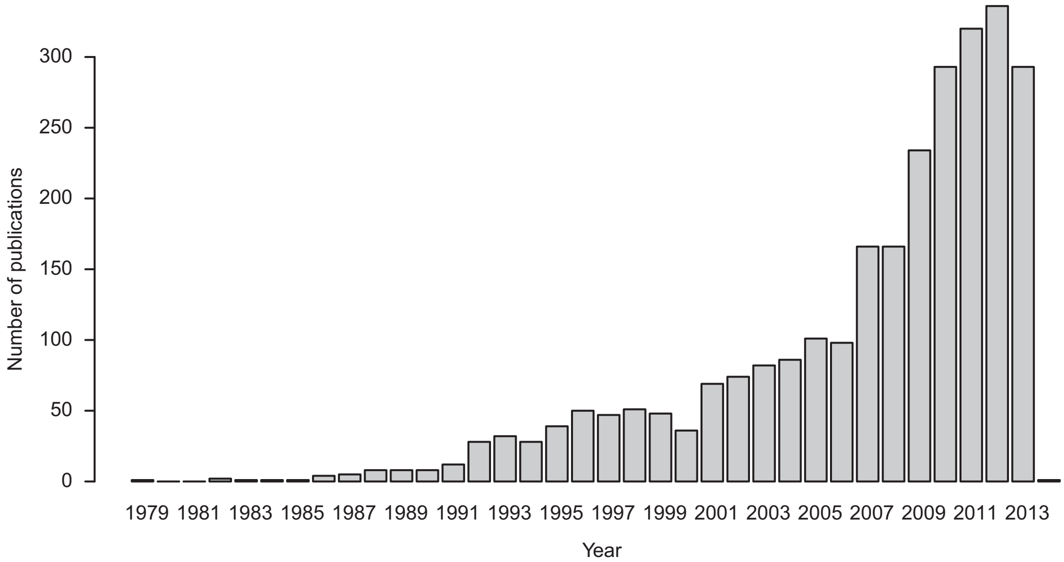

FIGURE 4.2 Increasing number of meta-analyses available from the ecological literature. Bars represent the number of primary publications containing the keywords "ecology" and "meta-analysis" published each year and available through the ISI Web of Knowledge database (papers published before 14 December 2013).

predetermined best analytical approach. Rather, they need to identify analytical approaches that fit data already collected. One way to address this is to consider gradients of environmental or human-induced conditions as treatment levels (Baum and Worm 2009) and select the analytical approach that can most efficiently exploit the identified experimental setting and available data. Below, we describe three methodological approaches that are particularly instrumental in integrative analyses.

Meta-analysis

The increasing availability of data described above has promoted a growing number of research syntheses (Figure 4.2). Meta-analysis is particularly suited for integrative historical ecological studies, including incorporation of data characterized by high uncertainty or limited information. In meta-analysis, values from individual studies are pooled in a larger experimental framework and treated as single data points. A study's uncertainty is used to weight the study's influence on the overall pattern so that data from studies with higher uncertainty have a lower weighting than those from more comprehensive ones, yet all data are exploited (Cooper and Hedges 1994, Normand 1999).

In such a framework, a test of a given hypothesis can reach statistical significance even though the composing studies are inconclusive or contradictory. This is because a meta-analysis increases statistical power by reducing the error of weighted average effect sizes (Cohn and Becker 2003). In ecology, where phenomena are multifactorial and often appear

BOX 4.3 Viewpoint from a Practitioner: Historical Data Revealed Massive Declines of Large Sharks in the Mediterranean

Francesco Ferretti

Mediterranean elasmobranch populations are among the most depleted in the world. This has been evident for decades in comparisons of FAO landings across world regions (Ferretti and Myers 2006), with multiple local analyses showing overexploitation of many shark and ray populations (Aldebert 1997, Jukić-Peladic et al. 2001, Ferretti et al. 2005, Cavanagh and Gibson 2007). However, a formal status assessment of all the species occurring in the basin came only in 2007, when the IUCN produced the first regional assessment of Mediterranean elasmobranchs. Of the 71 species assessed, 42% were Threatened, 18% Near Threatened, 14% of Least Concern, and 26% Data Deficient (Cavanagh and Gibson 2007). Most of the endangered species were assessed by using local aggregated or semiquantitative information such as changes in frequency of occurrence, sightings, and comparisons with qualitative descriptions, and by using a precautionary approach. However, few were based on periods >50 years (Cavanagh and Gibson 2007), and none relied on direct analyses of population change (McClenachan et al. 2012).

Following this, colleagues and I identified and assembled new data and qualitative information from additional regions and periods (Ferretti et al. 2008). These included sightings records from newspapers, museum and library records, commercial trawl catch data, landings from tuna traps, landings and observer data from pelagic longline fisheries, and catch statistics from recreational fishing clubs. Most of these data were available prior to the analyses in Ferretti et al. (2008) but had never been combined quantitatively to produce a regional synthesis.

We were able to select comparable data for five shark species or species groups—blue shark (*Prionace glauca*), common thresher (*Alopias vulpinus*), shortfin mako (*Isurus oxyrinchus*), porbeagle (*Lamna nasus*), and hammerheads (*Sphyrna* spp.)—estimating local trend analyses of catch per unit effort data (CPUEs) or other indices of abundance for each species. Instantaneous rates of change were also produced for each area and species and, as a common currency, were combined in a meta-analytical framework. The analyses revealed that over periods of 50–200 years, populations of these sharks had declined by 96% to 99%, implying a near extinction of these species in the Mediterranean Sea and,

contradictory and system dependent (Lawton 1996), meta-analysis has been effective in evaluating a broad array of questions, from testing the occurrence of top-down regulation in oceanic food webs (Worm and Myers 2003) and characterizing their dynamics (Micheli 1999) to assessing the nature and relative importance of interspecific interactions in animal communities (Gurevitch et al. 2000). Meta-analysis is also useful for assessing the status and extinction risk of species: inconsistent information on population trends, when evaluated meta-analytically, can reveal misclassification errors, such as classifying species to some lower risk category when the actual extinction risk is higher (Fernandez-Duque and Valeggia 1994, Ferretti et al. 2008). Box 4.3 provides a case study of these applications, using the example of sharks in the Mediterranean Sea.

according to IUCN criteria, a status of "Critically Endangered" in the region (Ferretti et al. 2008).

The results clearly warranted immediate conservation action and were communicated to the public through a coordinated outreach effort directed at translating the study's technical aspects and main findings into a language suitable for the greater public and policymakers. Consequently, the study received global media coverage, successfully bringing its finding to international attention, including that of interested political institutions.

In July 2008, the European Commission (EC) requested that the Scientific, Technical and Economic Committee for Fisheries (STECF) review these results. The STECF determined that combining different kinds of information was the only feasible strategy for addressing shark conservation status assessments, given a lack of long-term monitoring programs. The STECF further encouraged additional analyses of available time series in an attempt to reduce uncertainty (Anonymous 2008) and, importantly, advised that the EC implement a European Union (EU) Action Plan for Sharks. This included the establishment of bycatch reduction programs for Critically Endangered or Endangered elasmobranchs in instances where a zero Total Allowable Catch or prohibited status were not already in force for these species (Anonymous 2008).

On 5 February 2009, the EC adopted the first ever EU Plan of Action for the Conservation and Management of Sharks (European Commission 2009). Although the adoption of this policy framework was the result of the work of multiple nongovernmental organizations, international conservation bodies, and academic scientists, the empirical quantitative evidence provided in Ferretti et al. (2008) materially contributed to accelerating the EC's formal commitment to elasmobranch conservation (S. Maso, Shark Alliance, personal communication). The Action Plan did not impose fishery regulations for European sharks and rays, but it did create a new legal platform for developing specific legislation and management actions—for example, developing bycatch reduction programs for elasmobranchs in the northeast Atlantic and the Mediterranean and for four species caught by European fleets in the open ocean (Cavanagh and Gibson 2007, Gibson et al. 2008, Camhi et al. 2009).

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Bayesian Analysis

While meta-analysis relies on null hypothesis testing and thus evaluates the data while ignoring any previous information on the hypotheses being tested (McCarthy 2007), Bayesian analysts recognize that there is nearly always some previous knowledge about the process under study (Punt and Hilborn 1997, Wade 2000, Ellison 2004, McCarthy 2007; for an introduction to Bayesian statistics, see Kruschke 2010). In Bayesian frameworks, the likelihood or credibility of a given hypothesis (i.e., the posterior) is evaluated in light of previous information about the hypothesis (the prior) and the probability of the available data given such a hypothesis (the likelihood function). Existing information, such as historical semiquantitative or qualitative data, can be used in the construction of a prior probability distribution for the parameters under study, and in formulating the likelihood of the data given these hypotheses (Myers et al. 1995, Punt and Hilborn 1997). When a research question is clearly articulated and there is a clear definition of the analytical framework used to address it, historical and heterogeneous data can be incorporated into Bayesian analyses by translating information into probability distributions acting as priors of the Bayes rule.

For example, Gayeski et al. (2011) reconstructed historical populations of winter steelhead (*Oncorhynchus mykiss*) occurring in Puget Sound, Washington, from the nineteenth and twentieth centuries. They used multiple sources of information, including historical commercial catch reports from the late nineteenth century, data on the pace and extent of human settlement in the region, information on historical habitat extent, and other historical sources on the impact of aboriginal and European inhabitants. The authors used this information to build priors of total catch, catch rate, and unreported catch, and integrated these in a Bayesian binomial likelihood function to estimate posteriors of abundance of the overall local steelhead population and of subpopulations occupying different Puget Sound rivers. The authors integrated quantitative and qualitative historical information into quantitative stock assessment models. They estimated a discrepancy of population size between now and the end of the nineteenth century of about 25-fold. Their range of plausible population sizes (485,000–930,000) differed substantially from a previous official estimate (327,522–545,997) that failed to incorporate historical information on levels of steelhead catch by aboriginal peoples and early European settlers (Gayeski et al. 2011).

Newton (2010) provides another example relevant to Bayesian analysis and historical data: development of a quantitative framework for incorporating expert knowledge into assessments of species' conservation status. When the conservation status of a species is being assessed by the World Conservation Union (IUCN) and other similar bodies at the national level (e.g., the U.S. Fish and Wildlife Service, or the Committee on the Status of Endangered Wildlife in Canada), expert knowledge, including perceptions of historical change, is integrated into the assessment process, usually qualitatively and by consensus. However, this process is seldom conducted in a structured and objective way. Bayesian methods can be used to frame this process more objectively by constructing prior probability distributions from expert knowledge to be used in more quantitative assessments for data-poor species (Newton 2010).

Hierarchical Modeling

Multilevel hierarchical models can combine meta-analyses and Bayesian inference in a single statistical framework. Hierarchical modeling allows the analyst to incorporate multiple layers of information, including uncertainty on how the system works (process error) and on the measure of its state (observation errors; Parent and Rivot 2013). Probability models for the estimation of coefficients or the estimation of uncertainty can be plugged into higher-level models (Gelman and Hill 2006); hence, a variety of sparse and heterogeneous historical sources can be used to estimate different aspects of the ecological processes under investigation. Cornulier et al. (2011), for example, used a state-space Bayesian additive model to estimate change in hedgerow availability in the UK countryside to explain the loss of a farmland bird (the yellowhammer, *Emberiza citrinella*) previously detected by other studies. The authors collected multisource point estimates of hedgerow length and rates of change over time and developed a model of decline from these sparse historical data; original data were collected from several regions and periods, using variable protocols and levels of reporting detail. These authors stated that their modeling framework was highly generalizable and could be applied to the reconstruction of a time series of variables from "a variety of sparse and heterogenous historical sources" (Cornulier et al. 2011).

Information, when missing, can be borrowed from elsewhere. Gerber (2006) estimated historical trends in abundance of sharks and rays in the Gulf of Lion, southern France, by using a mix of Bayesian analysis and meta-analysis on aggregated trawl catch data (presence–absence). The author borrowed the dispersion parameters needed to characterize the species-specific negative binomial distributions of the catches from more detailed trawl-survey data recording similar species on the eastern U.S. continental shelf, and combined these dispersion parameters meta-analytically to construct informative priors necessary for the Bayesian trend analyses (Gerber 2006).

Integrative Analyses Stimulate Discussion and Further Work

Overall, attempts to integrate multiple datasets have led to useful debates and productive discussions that have advanced the field by making datasets available, contextualizing previously published data, and generating new hypotheses and research programs. Myers and Worm (2003), for example, analyzed historical time series of pelagic longline logbook catch data and fishery independent surveys to reconstruct steep declines of large predatory fishes from the onset of industrial fishing. This paper received worldwide media coverage and stimulated political and scientific discussions, including critiques of the authors' analytical approach and conclusions. These disputes had the positive effect of stimulating analysis and publication of large regional datasets refining the global patterns highlighted by this initial study (Hampton et al. 2005, Magnuson et al. 2006, Polacheck 2006, Sibert et al. 2006, Juan-Jordá et al. 2011). These and other analyses have shown that fish population trends differ regionally, with some species declining rapidly as a result of fishing, and others perhaps benefiting from the declines in predators or competitors (Myers et al. 2007).

Similarly, Worm et al. (2006) used historical FAO catch data to estimate the number of collapsed fish stocks and make projections about the future state of world fisheries, an approach that was heavily criticized (Murawski et al. 2007). The debate over the paper's conclusions ultimately promoted a larger collaboration between the authors and critics of the original study, which resulted in a further synthesis of the status of world fisheries (Worm et al. 2009). This collaboration partly resolved the disagreement and stimulated the assessment of unmanaged fisheries (Costello et al. 2012) and the development of the most comprehensive stock-assessment database available today (Ricard et al. 2011).

Uncertainty also has bounds, even in historical data. While researchers have disagreed about the details of estimates of historical population change, the overall magnitude and direction of change have generally emerged as points of agreement. Overfishing in New England, Canada, and the North Sea caused the collapse of multiple stocks of cod (*Gadus morhua*) in recent decades. Despite the variability of virgin biomass estimates across areas (Myers et al. 2001, Rosenberg et al. 2005) and disputes over the relative contributions of anthropogenic and species interactions in determining these trajectories (Hutchings and Myers 1995, Yodzis 2001), it became evident that fishing exploitation had to be reduced by at least half to preserve these stocks (Rosenberg 2007).

IMPLICATIONS FOR CONSERVATION AND MANAGEMENT

Moving from knowledge to actual conservation efforts requires effectively communicating such knowledge to policymakers and motivating them to take action. Public support is a crucial ingredient in this process. Integrative historical analyses can offer important insights into long-term population and ecosystem trends, patterns of decline or recovery, and baselines for conservation and management efforts. They can also play a key role in motivating and guiding conservation actions by rescaling our perception of what might constitute a natural level of population abundance for many animal populations, and helping document the magnitude of long-term population depletion (e.g., McClenachan and Cooper 2008).

Integrative historical analyses have the capability to engage and stimulate the imagination of the public through use of unconventional data (McClenachan et al. 2012). For example, by examining archaeozoological remains and the illustrations of fish in ancient Roman and Greek mosaics, Guidetti and Micheli (2011) found that the Mediterranean groupers (e.g., dusky grouper, *Epinephelus marginatus*) represented in these works of art were much larger than most of the animals seen today, and occupied shallower habitats than documented even at today's best-protected sites. These artifacts were not exaggerations, as the grouper sizes inferred from the mosaics in general were consistent with those estimated from bones found in archaeological sites. The peculiarity of the data source attracted worldwide media attention to the depleted state of these populations and to overexploitation of marine resources in general. Historical studies may also inspire policy changes, as has resulted from historical analyses of large pelagic sharks in the Mediterranean (Box 4.3).

CONCLUSIONS

Understanding long-term ecological processes and population trends requires an expanded approach to the synthesis and integration of data. However, several challenges to such approaches must be overcome; these issues range from a lack of inventories, organization, and standardization of the data available to the technical difficulties of making inferences from complex and heterogeneous datasets. Nearly all data types are amenable to being integrated into historical meta-analytical frameworks, but this process requires collaborative interdisciplinary approaches or requires ecologists to develop skills in areas outside their familiar bounds.

A key cultural shift will facilitate future scientific progress in using all available information in ecological analyses. Specifically, it will be important to move from seeking *precise* science to seeking *necessary* science. Integrative analyses are seldom precise but often offer broader perspectives on data that could rarely be achieved with conventional analytical approaches. While such analyses frequently attract criticism, they can also motivate action in the research, policy, and even political arenas. Movement on conservation issues is usually achieved by stimulating the imagination, interest, and engagement of the public, which consequently prompts political action for conservation.

Even though we recognize that the restoration of species or ecosystems to a relatively pristine state (defined through historical baselines) might not be feasible at present, if ever, providing evidence of the one-time existence of such baselines can enhance people's imagination about what might be possible. And once people understand such possibilities based on the past, they can make more enlightened decisions as to how to proceed into the future.

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