Introduction

Our modern society is exerting massive pressures on our biosphere. As of the 20th century we fix more fertilizer synthetically than all terrestrial plants are able to do combined (Galloway and Cowling 2002). CO2 emissions are higher than any other time in human history (Lunt et al. 2009). We have data too from ecological systems suggesting that they likewise have undergone massive change; extinction rates for example are at a minimum 100 times higher than any time during the past 65 million years (Ceballos et al. 2015). From losing mega fauna in the Pleistocene (Barnosky et al. 2004), to more recent disruptions due to species harvest or extirpation (Dirzo et al. 2014; McCauley et al. 2015) or disease introductions (Sinclair et al. 2007), humanity’s footprint is both broad and deep. Many geologists believe that these shifts will be apparent in the geological record and propose that we re-label our current era as the Anthropocene, distinct from the Holocene that came before (Waters et al. 2016). With these reorganizations of natural systems, comes the need for management. Yet conservation and management of natural resources is frequently a misnomer: often it’s not the ecology of these systems we’re manage, but our use of them with which we’re concerned.

To manage for continued human use, for sustainability, managers require a detailed understanding of the ecology of the systems of interest. Such an understanding can guide the types of use to allow. Historically much of the science upon which managers have relied to guide management falls in this category. However, as the scale of human pressure on our natural systems has expanded, it’s become clear that such biophysical science is necessary but not sufficient for sustainability (Castree et al. 2014; Hicks et al. 2016). Because management is an inherently social process and requires normative decision about for what to manage (Mace 2014), and because human use of the environment is difficult to entirely constrain, sustainably managing these systems also requires an understanding of how and why people use these resources. Because of these facts, understanding how to balance the tradeoffs between human well-being and ecological integrity is one of the largest challenge in natural resources management and conservation (McShane et al. 2011; Karp et al. 2015).

This quandary is particularly obvious when human well-being is a goal of management alongside that of ecological integrity. These mandates exist in most state-governed resource management units (i.e. fisheries (16 U.S.C. §§ 1801-1884), forestry (US Forest Service 2015), public lands in the US (Department of the Interior 2016)), but also in conservation organizations mission statements (The Nature Conservancy 2016; Conservation International 2016).

But understanding human well-being is also important because how people change their behavior as the distribution and abundance of resources change can result in unexpected and counter-intuitive ecological outcomes. Indeed, in my first chapter I extend a theoretical model to examine how a population of fish would be affected by the joint pressures of two stressors: climate change driven range shifts and harvest. In this model I explore not only the possible synergy of the two stressors, but also examine the outcomes of two common forms of management. I find that, while these stressors are approximately additive, the management recommended is sensitive to the assumptions made on how effort is reallocated (Fuller, Brush, and Pinsky 2015). This theoretical model, built with the aim of determining the sensitivity of marine fish to joint biophysical stressors, instead emphasizes the importance of understanding human behavior. This result dovetails with existing theoretical work suggesting that the dynamics of harvesters, i.e. how they respond to changes in the ecological conditions, can determine the stability of a system and ability to be managed sustainably (Tavoni, Schlüter, and Levin 2012; Lade et al. 2013). Empirical work is reaching the same conclusion, in 2009 Elinor Ostrom received her Nobel prize for pointing out under what conditions, ecological and social, societies can avoid the tragedy of the commons (Ostrom 2009).

This challenge of understanding how human well-being and ecological integrity interact is a challenge that exists across systems, terrestrial to marine, but fisheries systems offer an excellent system in which to examine it empirically. Fisheries are a good case study of human-environmental interactions in that fishermen are affected by both the ecological system (the spatial and temporal distribution and abundance of fish they target) and markets (price, demand and supply for fish). Commercial fisheries harvest is also important for the livelihoods of many people. Fisheries also make a good example because harvest is also an important, and sometimes major, ecological driver of these systems. There are a number of theoretical (Wilen, Smith, and Lockwood 2002; Smith and Wilen 2003) and empirical (Smith, Zhang, and Coleman 2008) examples in agreement with the theoretical results of my first chapter: that how people allocate effort spatially determines efficacy of management measures. Accordingly there is a great deal of interest in systems-level, integrated, social ecological management (P. S. Levin et al. 2009).

Commercial fisheries in the North America and Europe in particular are promising systems because of the large amounts of data which have been collected at big temporal and spatial scales. Indeed these fisheries have already been identified as a promising system in which to test many large scale ecological theories, due to the datasets describing the fish (Jensen, Branch, and Hilborn 2011). But these fisheries typically also have rich data on the people who harvest them, the fishermen. This data has been much less explored at a systems level. In the following two chapters I focus on the US west coast commercial fishery system using a dataset capturing landings for all commercial fisheries between 2006 and 2014 to developing new, nuanced ways of understanding how people interact with their environment.

Despite the increasing focus on valuing, and therefore measuring, human well-being alongside ecological quality indicators (i.e. biodiversity, ecosystem function), we still lack clear ways to operationalize these goals (Mace 2014). Developing new, nuanced methods for understanding how people interact with their environment and ways to describe them is important for advancing sustainability science (Hicks et al. 2016). This challenge is particularly acute in US commercial fisheries, where managers are mandated to manage both for the ecological viability of targeted species and the fishing communities which depend on them (16 U.S.C. §§ 1851), but not provided with a clear mechanistic understanding of how the sub-systems are linked.

In the US, fishing communities are legally defined by how much the region (approximated to the port) relies on commercial fishing as a source of revenue (16 US Code§ 600.345). Accordingly, existing research focuses on how people combine fishing with other economic sectors (Jepson and Colburn 2013; Pollnac et al. 2015). In the US, how people spread their effort within the fishery has never been effectively mapped or examined. In my second chapter I use the landings data on the US west coast to develop an approach to quantitatively link fishing communities (the social system) to individual fisheries (the ecological system). This approach is a novel conceptual framework and advances our understanding of the system-level human connectivity amongst fisheries. This analysis reveals the existence of system level properties that may be useful heuristics for managers to use in evaluating adaptive capacity of these fishing communities. In particular, I reveal the possibility of “keystone fisheries” and that these fisheries systems display an intermediate scale of organization not previously identified.

Because the appreciation of the interconnectivity of marine systems is still relatively recent and the inclusion of people in these networks nascent, there are to my knowledge no published studies empirically examining how these system-level properties change as a function of management. Yet to effectively manage social ecological systems such studies are necessary to choose among policy options. In my third chapter I contribute to filling this gap by making use of the systems-level analysis described above to analyze how a major change in the management of a single fishery affects the human connectivity of the US west coast commercial fisheries system. Thanks to the rich data, I am able to conduct this analysis at two scales: that of the individual fishing vessel and the fishing community, contributing additional nuance to the results. I find that fishermen have changed their patterns of participation across fisheries as a function of how they were affected by the management change but the system-level properties remained unchanged. While the goal of the studied management change had nothing to do with the larger fishery system, this work demonstrates how such systems-level policy evaluations could proceed.

In this thesis I present theoretical models, a conceptual framework and empirical analyses focused on the question of how to quantitatively and comprehensively include people in food webs. This work helps move us towards a set of tools managers can use to evaluate policy efficacy in commercial fisheries social ecological systems in the face of rapid environmental change while balancing the need for ecological integrity and human well-being.

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