**Abstract**

**Introduction**

Ecosystem-based management (EBM) has become the approach du jour of ocean and coastal conservation and stewardship, appearing prominently in an array of highly visible policy documents *(Pew 2003, USCOP 2004, and EO 13547 2010, Australia’s Ocean Policy (DEWR 1998), Canada’s Ocean Act (GC 1996), the European Marine Strategy Framework (EC 2008), and the Convention on Biological Diversity’s Ecosystem Approach (CBD 2000)*. The shift towards EBM is motivated by a combination of real and perceived concerns, including conflict between ocean users (Crowder and Norse 2008), poor coordination across governing bodies (Norse 2010), failure to adequately sustain living marine resources through single-species management (Jackson 2001, Worm et al 2006), and increasing recognition of the complex, non-linear, and coupled human-natural interactions within marine systems (Wilson…). However, despite the increasing emphasis on EBM, the transition from EBM in theory and policy to practice has been slow (Pitcher et al. 2008). This slowness, in part, underscores the technical and scientific challenges that underlie EBM and the uneven, sometimes contradictory, and difficult task of understandings of the social-ecological structure of marine ecosystems (Evans and Klinger 2008).

In the last decade, numerous efforts have been waged to better define (e.g., Slocombe 1998, EPAP 1999, Pikitch et al. 2004, McLeod et al. 2005) and forward EBM (e.g., Curtin and Prellezo 2010, SPC 2010, Heenan et al. 2013, Pomeroy et al. 2013). This progress is often cast as a sharp departure from traditional, single-species management regimes (Chapin et al. 2009), though Link (2002:19) has challenged the “apparent duality” between existing fisheries management and proposed EBM strategies, arguing that there is a “gradient of approaches” along the continuum of management decisions that exist. Aswani et al. (2011:1) offer a similar view, arguing that EBM “is best thought of as an expansion of customary management and integrated coastal management, rather than a paradigm shift.”

Much of the research in this burgeoning domain of science has sought to illuminate the connectivity within and between the biotic and abiotic components of these systems, using sophisticated modeling approaches such as OSMOSE, Ecopath/Ecosim, and Atlantis. For example, the latter is used in the integrated ecosystem assessment (IEA) framework proposed by Levin et al (2009) and adopted by the National Marine Fisheries Service to guide management decisions. Atlantis, like others, can be used to model simple trophic interactions and more highly complex ecological structures (Flower et al. 2013). These efforts represent progress along Link’s conceptual gradient, but focus almost exclusively on the ecological components of these systems, without consideration of the social or economic influences that interact across time and space. Understanding these human interactions therefore represent an important frontier to EBM science.

In this paper we aim to contribute to this gap by presenting an approach for measuring human connectivity of fisheries at individual and community level and use it to evaluate how a change in management affects anthropogenic connectivity in US west coast commercial fisheries. We employed a novel clustering algorithm to determine commercial fishing strategies along the US west coast. We found that the algorithm correctly identified spatial and temporal patterns of known single – and multispecies fisheries, and used the classification method to (i) determine vessel-level participation in individual fisheries and emergent diversification of their participation across fisheries, and (ii) describe networks of fisheries participation for entire communities (ports). We found that the majority of vessels examined were generalists, which participated in more than one commercial fishery in our time-period. In addition, interconnectedness of fisheries participation varied strongly across ports. Using these individual and community-level measures of fisheries diversification, we evaluated how the introduction of a new management structure influenced vessel-level participation in the affected, along with diversity measures for vessels and ports as a function of their participation in the affected fishery.

We hypothesized that catch shares would affect fishing strategies in one of two ways: causing vessels to either drop out of the fishery or, for those that remained in the fishery, allowing them to diversify by participating more heavily in other fisheries. For port communities, we tested whether changes at the vessel level were reflected at the port-level. We found that the implementation of catch shares caused a minority (6%) of vessels to leave commercial fishing altogether, while 53% of vessels continued to participate in the affected fishery and diversified by participating in additional fisheries, only 13% of vessels continued to participate in the affected fishery with fishing participation unchanged A third group consisted of vessels that exited catch shares but continued to fish commercially (28%). These vessels showed a mixed response, with increased and decreased fishing diversity observed. We also found that these changes at the vessel-level did not affect participation among fisheries at a community level. This work helps to formalize and quantify social ecological linkages across scales.

**Discussion**

We find that more than 60% of fishermen are generalists, effectively connecting the multiple fisheries in which they participate. This finding runs counter to conventional ways of thinking about fisheries systems. Historically theoretical models of fishing have defined fleets as homogenous groups of specialist vessels focusing a set of species with a particular gear and ignoring the other fisheries in which the vessels may participate (refs). Following these formulations, most empirical analyses have also taken a similar approach (refs). Even ecosystem based management, with a focus on systems-level analyses and species interactions, treats fleets as unconnected (refs). This gap is problematic as fisher behavior is central as it will mediate how changes in management translate into changes in the ecology and human well being of ecological and social the social ecological system ecological and changes in the marine environment (refs).

Ecologically, there is a large literature demonstrating the importance of accounting for apparent competition, where the competition between two species is obscured by the predation by a common predator. Failing to account for apparent competition has resulted in being unable to predict the impact of extinction in a food web (refs). Similarly, failing to account for the anthropogenic connectivity among fisheries may result in changes in one fishery unexpectedly affecting the participation in a fishery targeting a species which is ecologically unconnected. Dungeness crab and albacore tuna fisheries on the west coast provide an appealing, but untested example. There are myriad examples of the importance of properly characterizing ecological connectivity both for better understanding of species responses to perturbations and management change. Indeed ecosystem based management is largely a response to the lack of connectivity provided in traditional single-species fisheries management. Similarly, recent work on bushmeat and artisanal fishing has highlighted the importance of recognizing the connections between these activities in order to provide adequate alternatives to relive pressure on scarce wildlife (refs).

As management agencies have shifted from single species to system-level management goals these holistic management goals are accompanied by policy language explicitly valuing human wellbeing alongside ecological integrity (refs). EBM modeling approaches and empirical studies focusing on species interactions have gone a long way to help understand and conceptualize marine ecosystems ecological connectivity, however understanding the human scale is still a challenge. In EBM models, humans are represented as fishing fleets (refs). Fleets are not unlike predators with a set of prey selectivities, and these fleets may grow in size, or change effort levels depending on revenue. Changes in human wellbeing then, can only be modeled as changes in fleet revenue. Yet here we demonstrate that a single vessel on the US west coast is likely to participate in multiple fleets. The social implications of this generalism have been most directly related to reduced exposure to financial risk (refs). Previous work has demonstrated that vessels with increased participation diversity have less variable revenues, and that changes in management have been associated with reduced participation diversity in these fisheries (refs). Thus measuring participation diversity across vessels before and after a management change helps to understand how changes in system characteristics affect one facet of human well being.

We document the generalism present among US west coast fishing fleets, but also that the implementation of catch shares has increased revenue diversity at the vessel level for vessels that continued to participate in the fishery. If previously documented relationships between vessel participation diversity and revenue variability hold, catch shares thus has reduced these vessels’ exposure to risk. It’s important to note, however, that not all groundfish trawl boats made the transition into the catch shares regime. Based on our analyses, it appears that smaller, more diversified boats were not as likely to continue fishing in catch shares. Most analyses of the impacts of catch shares have focused on the vessels that continue fishing, assuming that vessels that exit also exit commercial fishing. This work demonstrates that the majority of vessels continued fishing, albeit in other fisheries. Closely examining what happens to these trawlers that exited groundfish fisheries, and whether these patterns in of connectivity can predict new entries is an important next step for this work.

Most people talk about impacts of just vessels in fishery rather than all vessels and/or community. By conducting analyses at a certain scale, we lack the full picture (refs). We find that the effect is the same, but attenuated, at the community level, but too little work has been done for us to know if that result is general. This is worth further study empirically and theoretically, since many management groups are mandated to consider community and vessel level changes (refs). We know a lot more about vessels and a lot less about how to meet legal commitments at community level.

The goal of this work is largely exploratory, to develop ways of quantitatively measuring changes in human connectivity as a result of a management intervention. And it should be cautioned that our time series is short, and fishing fleets will continue to adjust to the management changes. We also recognize that there are many possibly appropriate scales at which to conceptualize a “fishing community” and that these communities are affected by much more than just fisheries. Similarly we also recognize that fishermen frequently have employment outside of the fishing industry, vessels constitute more than one person. To more fully include the social aspects of these SESs all these issues need additional attention.

In this work we show how measuring and mapping human connectivity of marine systems can help develop human components of EBM models that better reflect the human scale. Due to human connectivity among fisheries, changes in one fishery revenue may affect human well being, even if no impact is felt in the focal fleet. Our work here provides a method of determining ecologically realized fisheries, and mapping a vessel’s participation across them. An important next step would be to develop fishing portfolios, or characteristic combinations of fisheries that vessels participate in annually, in order to better map changes in marine species abundance and range to changes in fishing livelihoods.