Scale Matters

Relating Wetland Loss and Commercial Fishing Activity in Louisiana across Spatial Scales

Amy Freitag, Suzana Blake, Patricia M. Clay, Alan C. Haynie, Chris Kelble, Michael Jepson, Stephen Kasperski, Kirsten M. Leong, Jamal H. Moss, and Seann D. Regan

Abstract: Interdisciplinary science and environmental management involve bringing together data and expertise at multiple spatial scales. The most challenging part of merging scales is aligning the scale of inquiry with the research application. Through the Louisiana case study relating wetland loss and commercial fishing, we examine how the nature and strength of the relationship changes depending on the scale of investigation. Resulting management implications also vary because of tradeoffs in choosing the scale of inquiry. State-level fisheries managers may miss effects of wetland loss in fishing communities because they are looking at aggregate data. Scientific information must directly address the constituent scale, where managers can enact policy. The case study demonstrates why scalar considerations should be an explicit part of the planning process for both science and management.

Keywords: commercial fishing engagement, ecology, fishing, spatial scale, wetland loss

Environmental management has been increasingly moving away from single species management toward ecosystem-based fisheries management (EBFM) at scales that encompass multiple jurisdictions. The first efforts in ecosystem-based management occurred in terrestrial environments with their relatively clear property rights; this has resulted in the development of many spatial tools to address problems at a variety of scales (Apitz et al. 2006). Wetland habitats tend to be challenging, however, due to the diversity of wetland types and overlapping, fluid property regimes; standard terrestrial tools applied to these habitats are inadequate at best (Adger and Luttrell 2000). In marine ecosystems in the United States, the National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) has adopted a policy of ecosystem-based fisheries management (NOAA Fisheries 2016) and has been developing tools to assist in its implementation,

Nature and Culture Volume 17, Issue 2 Summer 2022 144–169
doi:10.3167/nc.2022.170202 ISSN 1558-6073 (Print) · ISSN 1558-5468 (Online)

such as the Integrated Ecosystem Assessment (IEA) framework. One of the hallmarks of IEA is integrating diverse elements of the ecosystem, from oceanographic and climate influences to ecological and social systems (Levin et al. 2009). These processes inherently act at different scales and therefore explicit attention to scale and inter-scale interaction is necessary to implement EBFM, particularly to connect human concepts of place to other ecosystem components (Leong et al. 2019). Attention to scale will highlight additional aspects of a given policy problem as well as roadblocks to policy implementation that arise from incompatible cross-scale interactions.

When a scientist chooses a scale or scales of inquiry, they also inherently choose the ecological and social dynamics that are associated with that scale. Because a spatial scale is associated with each specific ecosystem service (e.g., food provision, climate regulation, nutrient and oxygen production, and cultural benefits [Millennium Ecosystem Assessment 2005; Hattama et al. 2015]), the decision of what scale or set of scales should be examined needs proper alignment with the questions being asked. When science is applied in environmental management, the scale of inquiry is often set at the scale of the management jurisdiction in order to be most helpful to decisions on the policy agenda; in Louisiana these decisions are at the state or larger scale. However, this default scale choice can create a mismatch between the scale of ecological and social dynamics that affect and are affected by the management system and the scale of the management jurisdiction itself, as shown in both marine and terrestrial systems (Jordan et al. 2012; Raudsepp-Hearne and Peterson 2016; Grêt-Regamey et al. 2014; Cheung et al. 2018). We explore these potential mismatches by examining the relationship between commercial fishery and wetland dynamics in the state of Louisiana in the United States. This relationship is hard to detect at the scale of the management jurisdiction (state-wide or Gulf-wide fisheries monitoring and management) but is visible at the human community level. Below, we discuss the theory behind choices of scale and then provide some insights into choosing appropriate scales through discussion of the Louisiana case study.

The Theory of Scale

Because the typical scale of inquiry varies across scientific disciplines, even beginning a discussion of scale in a multidisciplinary management context is difficult. A review of the term across social and ecological disciplines found that scale is most often discussed in a discipline-specific methodological context (Silver 2008). The review suggests future studies look at the socioecological systems literature for examples of successfully blending disciplinary scale concepts to address environmental management problems. Some integrative synthesis projects, including the NOAA IEA program, have taken this approach successfully (Okamoto et al. 2020; Lazzari et al. 2019; O'Higgins et al. 2019; Samhouri et al. 2017). Similarly, we treat scale as a concept comprised of spatial extent and spatial resolution of the units of inquiry within that larger extent. For example, a state management agency will often need to make decisions at the scale of the whole state (the extent), although they may examine data at finer spatial resolutions such as for each county or each community within the state.

The study of economics has focused on space for many years, beginning with Harold Hotelling (1929) describing the importance of neighborhood economic dynamics and extending into more recent decades with the work of Paul Krugman and Anthony Venables (1995) after globalization removed some of the economic "seams" of society. Choice of scale also affects the large literature related to environmental Kuznets curves, a hypothesis with mixed and inconsistent empirical evidence (e.g., Stern 2004, 2018, Gallagher 2009) that posits an inverted U-shaped relationship between income and pollution (Dinda 2004). It also impacts interpretation of that data as transferred to development policy (Tsurumi and Managi 2010). Over the years, economists have attempted to empirically define scale through the scope of economic transactions and their effects, which often reach far beyond official political or social boundaries.

Roderick Neumann (2009) also suggests the need for a transparent, explicit process of defining scale in each research endeavor and of situating that scale in the context of other cross-scale dynamics, as well as shifting definitions of scale as underlying socioenvironmental relationships change. Adam Moore (2008) points out that even with conflicting and confusing definitions of scale, defining scale as a category of analysis in advance can be helpful. This provides a statistical basis for choosing scale rather than relying on a sometimes arduous policy negotiation. In fisheries economics, for example, the definition of the spatial and temporal scale at which fisheries operate is a key element of explaining fisher behavior (Abbott and Wilen 2011).

Dealing with Multiple Scales

Given the context-dependent definition of scale and prescriptions for defining scale, an important step in defining scale for an environmental management issue is determining the scale at which humans interact with their environment in the context of the management issue at hand. Furthermore, defining the scale should also define critical cross-scale linkages including knowledge co-production, mediation, translation, and negotiation in order to facilitate solutions (Cash et al. 2006). Using commercial fishing as an example, this involves measuring how far from home fishers will fish and the range of environment types and conditions over a given space that lead them to make decisions about their fishing behavior. It also involves the human scales of crew, family, and community wherein those decisions are made as well as the social and economic choices connected to environmental and technological options available at any given scale. The scales of human interaction are often much smaller than the scale of the management jurisdiction or the ecological range, creating a scalar mismatch between humans, ecology, and management. In the short term, these mismatches can be addressed by institutional changes to allow for nested hierarchies of management; longer term solutions additionally depend on flexible institutions that can react to environmental change (Cumming et al. 2006). In scientific inquiry, scale mismatch is often an artifact of building a model or experiment without a specific question or management outcome in mind. In reality, just like management, scientific approaches need to be flexible and scalable to meet the needs of evolving scientific and management priorities (Harvey et al. 2017).

Addressing a nested hierarchy of scales also allows for explicit inquiry into any cross-scale interactions. Different scales of social interactions (individual, group, community, society) affect the values attributed to ecosystem components, and social and environmental drivers often operate at different scales in space and time (Small et al. 2017). For marine systems, work on tipping points (the point at which an ecosystem transitions into a new state [Hicks et al. 2016]) and regime shifts suggests that a regime shift in one scale can cause a domino effect of tipping points in other geographic scales, or a subsequent regime shift, but the exact mechanism is context-specific (Rocha et al. 2018). More optimistically, marine animals with large ranges or migration routes that move across national boundaries also exemplify the mismatch between social and ecological scales, but their management provides an example of multiscalar nested management in order to meet ecological needs through the cooperation of smaller-scale social institutions (Havice et al. 2018).

One of the most important mechanisms for crossing scales in the social and/or management sides of the system is communication strategies that work both within each scale and across scales, like stakeholder meetings in individual communities that can be synthesized at the national (or regional) level for policy purposes (Wyborn 2015). The timing of this communication is also key; communication across scales of both research and management should be incorporated early in the process, during project planning, with both project partners and potential end users. For example, because of the level of detail achievable in a case study, early small-scale studies can help create tangible examples of phenomena that happen at regional or national scales. These studies can then serve as inspiration for repeated or scaled-up studies.

Ecosystem services, defined as the benefits that people obtain from ecosystems, are commonly divided into four categories: provisioning, regulating, supporting, and cultural (Millennium Ecosystem Assessment 2005). Direct provisioning of human needs by the ecosystem is perhaps the easiest to understand and most direct link between humans and nature. Attempting to enact policies that ensure continued provision of ecosystem services, by protecting the ecosystem features that provide them, can make apparent the scale mismatches between human well-being, ecosystem function, and governance institutions (Duraiappah et al. 2014). The scale of observation of ecosystem services was found to make a difference in study conclusions especially for provisioning and cultural ecosystem services that rely upon resources with patchy distribution (Raudsepp-Hearne and Peterson 2016). Since observation is the first step of both further research and management, choosing the scale of observation carefully is critical to being able to relate those observations to the outcomes of interest.

Fisheries in Louisiana offer an ideal case study opportunity to investigate the effects of choosing different scales of observation, as there is abundant data for multiple scales of inquiry, potentially leading to a better understanding of how cross-scale processes can directly facilitate EBFM. Fisheries are a provisioning service that depends on patchy and dynamic habitat distribution (wetlands), which is linked to important regional cultural ecosystem services.

Background on the Louisiana Case

Wetland loss is a worldwide issue linked to decreases in human well-being in neighboring communities and changes in global ecological processes (Millennium Ecosystem Assessment 2005). The Mississippi River Delta exhibits some of the fastest wetland loss in the world, estimated at 75 square kilometers annually, due to a combination of sea level rise and subsidence hastened by human engineering, while some of this loss goes through multiple transitions as much as 75 percent is estimated to transition directly to open water (Roy et al. 2020; Cowan and Turner 1988). In Louisiana, wetland loss is projected to lead to an increase in the magnitude and frequency of storm-surge flooding and related disruptions in the social and economic life of its residents, especially those in the coastal band and outside of the levee system (Royal Engineers and Consultants, LLC and Earth Economics 2016; Condrey et al. 1995). Other devastating effects include losses to businesses, residential structures, and transportation infrastructure (Barnes et al. 2015). Further, as land loss increases, oil and gas infrastructure will be exposed to the elements, resulting in an increased risk of oil spill accidents, compounding the risk of social and economic loss (Barnes et al. 2015).

Many residents in coastal Louisiana are highly reliant on fishing occupations. According to NMFS, its ports consistently report some of the highest landings nationwide. Wetland loss impacts the commercial fishing industry, as wetlands provide critical habitat for commercial fishery species (Minello et al. 2003). Wetlands provide both escape habitat for these species to hide from predators, nesting material and protected habitat for eggs as well as larval and juvenile fish, as well as food for both herbivorous and carnivorous fish (Boesch and Turner 1984). Additionally, the network of pools and channels associated with marshes provides important habitat for juvenile fish (Jennings et al. 2009). A frequently used example of shrimp in the Gulf of Mexico shows that yields are observed to be linearly related to the quantity and quality of wetland habitat (Turner and Boesch 1988). Edge habitat is perhaps the most important part of the wetland in relation to commercial fisheries, due to both the importance of edge structure in providing the benefits of wetlands to fish (hiding spots and food) and the benefit of access for fishermen to catch said fish (Chesney et al. 2000).

Wetland loss could lead to devastating disruptions to the economic and social life of the local communities in these coastal areas, including loss of culture and heritage. Julie Maldonado (2014) shows how, due to historic patterns of uneven power structures, the impacts of land loss are unequal and multifaceted. For example, the community of Isle de Jean Charles has lost almost 80 percent of its area, and similarly almost 80 percent of its population since 1963. Much of the day-to-day experiences, identity, culture, and heritage of people in places like the Isle de Jean Charles are deeply intertwined with the wetland landscape, on which they depend not only for food, water, and medicinal plants but also for a sense of belonging, connection to their past and heritage, and hope for the future. The drastic change in this landscape has led therefore to alienation and uncertainty about the future for island residents, most of whom are Native American (Maldonado 2014). Other fishing communities, whether tribal and indigenous or simply generational, face similar loss of social connections, cultural identity and sense of place due to environmental change and changes in ecosystem services (Hausman et al. 2016; Masterson et al. 2017).

To slow down the pace of land loss, in 2016 the state of Louisiana proposed a coastal restoration master plan that comprises more than 120 wetland restoration projects (Coastal Protection and Restoration Authority of Louisiana 2017). Many of the proposed restoration projects, like sediment diversions, are experimental in nature and therefore extremely controversial. While the state of Louisiana views these projects as an exemplar of wetland restoration for the world, the residents invested in the local seafood industry, for example, worry about the impacts of these projects on the local estuaries on which their livelihoods depend (Barra 2016).

For Louisiana, past studies have yielded a mixed set of results when attempting to quantify the relationship between commercial fisheries and wetland loss. Worldwide trends (Millennium Ecosystem Assessment 2005) and research on the shrimp fishery specifically (Turner and Boesch 1988) suggest that commercial fishing catch will decline as wetland habitat loss increases. Yet, other fisheries in the Gulf suggest Louisiana fisheries may be especially resistant to habitat loss (Chesney et al. 2000). Part of this divergence is due to edge effects giving a temporary boost to some fishery species (Lewis et al. 2016) and another part may be due to time series not being sufficiently long enough to adequately capture the changes associated with wetland loss (Chesney et al. 2000). A third part of the difference in effects of wetland loss may also be ascribed to fishing behavior; a better understanding of this behavior as tracked by vessel monitoring systems (VMS) in the grouper-tilefish fishery has already improved stock assessment models (Watson et al. 2018). VMS data also reveals that exploration, or the ability to utilize multiple fishing grounds, may help buffer the impacts of hurricanes and other wetland loss events in the Gulf (O'Farrell et al. 2019).

While there are likely multiple reasons why the relationship between commercial fisheries and wetland loss in Louisiana is unclear, one area of needed research is addressing whether the relationship changes depending on the scale of inquiry. Edward J. Chesney, Donald M. Baltz, and R. Glenn Thomas (2000) suggest that relationships may change over time or thresholds may be crossed before or after data are available, or that the story of resilience they found at the state level may not hold true for specific communities much less individuals. Provision of ecosystem services needs to be studied at multiple scales to understand how dynamics may vary depending on the scales at which they are measured (Engle 2011) and how the relationships between scales affect the provision and distribution of ecosystem services to their beneficiaries (Martin-Lopez et al. 2019). Given the mixed results in past studies and rapid pace of environmental change, general statements are of mixed utility. Therefore, here the specific relationship between Louisiana commercial fisheries and associated wetlands will provide a case study for examining differences in ecosystem services provisioning across different spatial scales.

Our primary hypothesis about the Louisiana case study is that the spatial scale of observation chosen will make a difference in how wetland loss affects fisheries (or even whether any effect is apparent at all). If this hypothesis is correct, additional research will be necessary to examine which scale(s) of analysis provides actionable information needed for a given management issue or how information from multiple scales can be most productively integrated. Furthermore, we hypothesize a mismatch between the scales of management, scientific theory on the subject, and availability of data for the Louisiana case.

Methods

For the case study, the first step in looking at the relationship between commercial fishing and wetlands was to choose indicators for each; this choice is a balance between the data that would best reflect the ecological and social dynamics of interest and the availability of secondary data. For wetland loss, we chose aerial photography and remotely sensed time series compiled by USGS (Couvillion et al. 2011), which spanned the years 1932 to 2010, with a spatial resolution re-sampled and aggregated to 30 meters matched across all data sources. The main benefit of this dataset is that it combines remote sensing data from satellites with historical and aerial surveys and integrates these with newer remote sensing technologies as they evolved over time, and thus provides a comprehensive high resolution spatially defined time-series perspective on wetland loss in coastal Louisiana. In order to test correlations across scales, the wetland loss change data was evaluated at four spatial scales: local trip ticket zone, community, parish, and watershed (see Table 1 for number of each).

At the smallest scale, Louisiana tracks fishery catch by trip ticket zones (see Figure 1 for a map). For a medium-scale, we chose community, as defined by Census Designated Place and neighboring navigable waters accessible by small fishing boats. At this scale, fishing from several trip ticket zones is aggregated into town/community-based markets, where one would find the dealers and other land-side support business for the fishery. For the largest scale, the results should be relevant to a management agency, be related to the scale of human activity, but offer enough individual sites to run statistical correlation tests. We chose to look at both ecological and social options for defining the larger scale: watersheds and parishes.

Community level was calculated as area accessible via navigable waterways within approximately one hour of time by a fishing vessel from each Census Designated Place on the Louisiana coast. Personal communications with local fishermen (2018 Lafitte field trip, Belle Chasse Stakeholder Workshop 2018) as well as the average straight line distance calculations done by Stephen Barnes and colleagues (see Barnes et al. 2015, Appendix tables) support our choice average distance typically traveled by fishermen to reach fishing grounds. Barnes and colleagues (2015) shows that while there is some variation, many of the commercial fishermen in this region reside in close proximity to the fishing grounds they use to sustain their way of life as defined

Table 1 ■ Number of zones for each scale present in Louisiana

Scale	**Total N**
Local trip ticket zone	64
Community	57
Parish	11
Watershed	10

in specific fishing communities (Brookfield et al. 2005; Mederer 1999; Sowman and Sunde 2018) and livelihoods (Van Ginkel 2001). For example, the average distance traveled from home to the fishing grounds for oyster harvesters in the Barataria Basin was 39 miles in 2014; for crab harvesters it was 15 miles, and for shellfish 21 miles. This information is important when we consider the scale at which fishermen interact with the wetlands as this is likely the scale most relevant to their economy, culture, and overall perception of wetland health.

Navigable waterways data used in this analysis were derived from the USGS National Hydrography Dataset (US Geological Survey 2019). Polylines of navigable waterways were built into a network dataset, and distances of 10 nautical miles away from Louisiana community centroids were calculated (10 nautical miles is equivalent to roughly one hour of travel time). From this, polylines buffers of half a mile were created to estimate the amount of wetland loss at the community level.

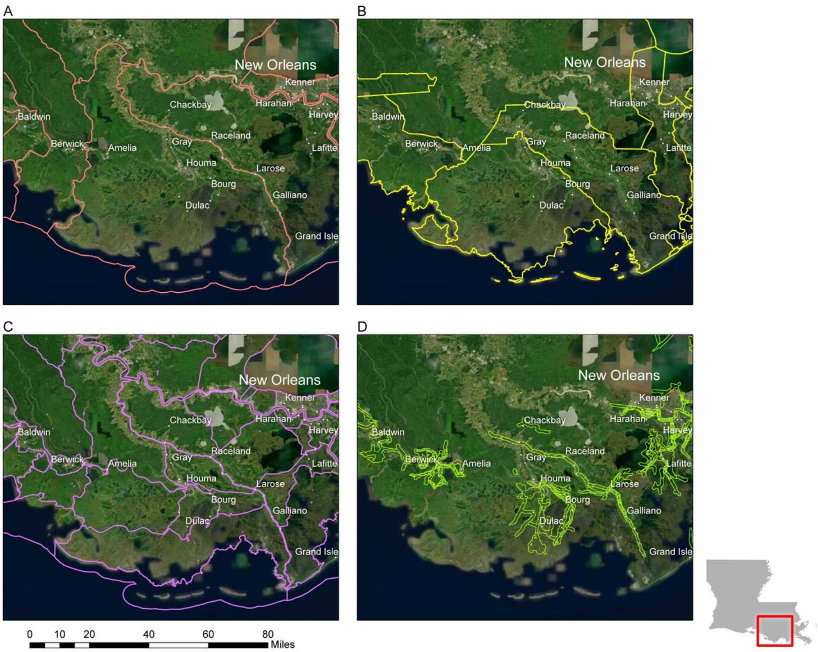

Figure 1 ■ The four scales of inquiry: (a) watershed, (b) Parish, (c) trip ticket zone, and (d) community network. The area of inquiry includes all coastal parishes (and sub-geographies) in Louisiana. The red area in the inset map indicates a subset of this data for visualization purposes.

Commercial engagement is one of four indicators developed by NMFS to assess community involvement in fishery resources (Jepson and Colburn 2013) and portray the importance of fishing activities in a community. It is an indicator comprised of four variables: value of landings, pounds of landings, number of commercial fishing permits, and number of fish dealers with landings, which are then combined via principal components analysis (PCA) into a final index; data from this publication for the community level is available online.[1] We obtained data for each of these metrics for each of the Louisiana trip ticket areas from the NMFS Southeast Fisheries Science Center. Data for larger geographies were aggregated from the trip ticket zone data using the Summarize Within Tool in ArcGIS. Trip ticket zones that fall across parish or watershed boundaries were assigned to the parish or watershed containing the majority of its area.

As a means of looking at some indicators that are directly connected to wetland resources in particular, we also looked at landings of wetland-dependent fishery species: blue crab, Eastern oyster, and northern brown shrimp. These data are a part of one of the components of the commercial engagement index. These species depend on wetlands for nursery habitat and food sources, but have very small home ranges compared to other large fisheries in the region, and so can be theoretically tied to a particular patch of wetland. As such, they are meant to serve as a more geographically relevant and specific commercial engagement measure.

Correlations between wetland loss and commercial engagement, wetland loss and fishery landings, wetland loss and change in commercial engagement, and wetland loss and change in fishery landings were tested by a Spearman correlation in RStudio. These variables were chosen because they all represent some of the most direct linkages between humans and wetlands—direct provision of food from wetland species. Several options for indicators of both the fishery status and wetland condition were tested to identify the most direct relationship. Note that these correlations describe the relationship between two variables but do not establish causality. Additionally, each of these variables exists in a complex system with direct influences and effects on either side of the relationship. It is also possible that despite the apparent simplicity, intervening variables are present between fishery and wetland status; these possibilities will be discussed in the conclusion.

Results

How does wetland loss appear across the different scales? Just looking at wetland loss across time, the local, parish, and watershed scales all show variation in wetland loss, with a simultaneous dip around 2005 (right after Hurricanes Katrina and Rita). However, at the community level, the pattern looks slightly different—the dip is not as apparent in 2005, and there is a smaller, prior dip in the early 1990s (possibly due to Hurricane Andrew). Note that the community scale is not comprehensive of all the wetlands, but instead represents just the wetlands that people can access via waterways within an hour's travel for any given fishing trip. The difference in dynamics between scales points to the finding that much of the recent wetland loss is beyond the typical travel distance of a community resident. Also note the time scale for each interval is not consistent due to the available data sources (recent years are available at more intervals), so the important differences are between scales, not between time periods.

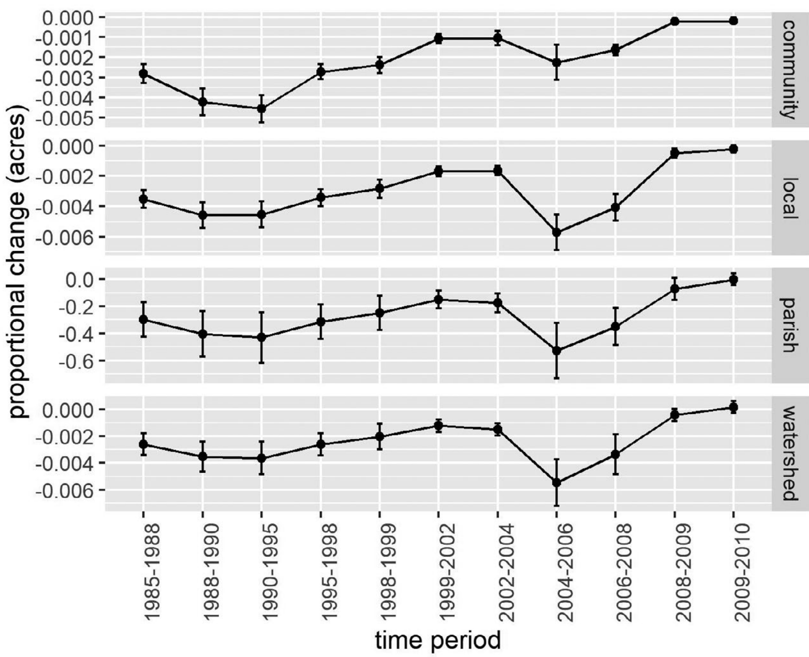

Figure 2 ■ Wetland loss over time for each of the four study scales for coastal regions (areas containing wetlands).

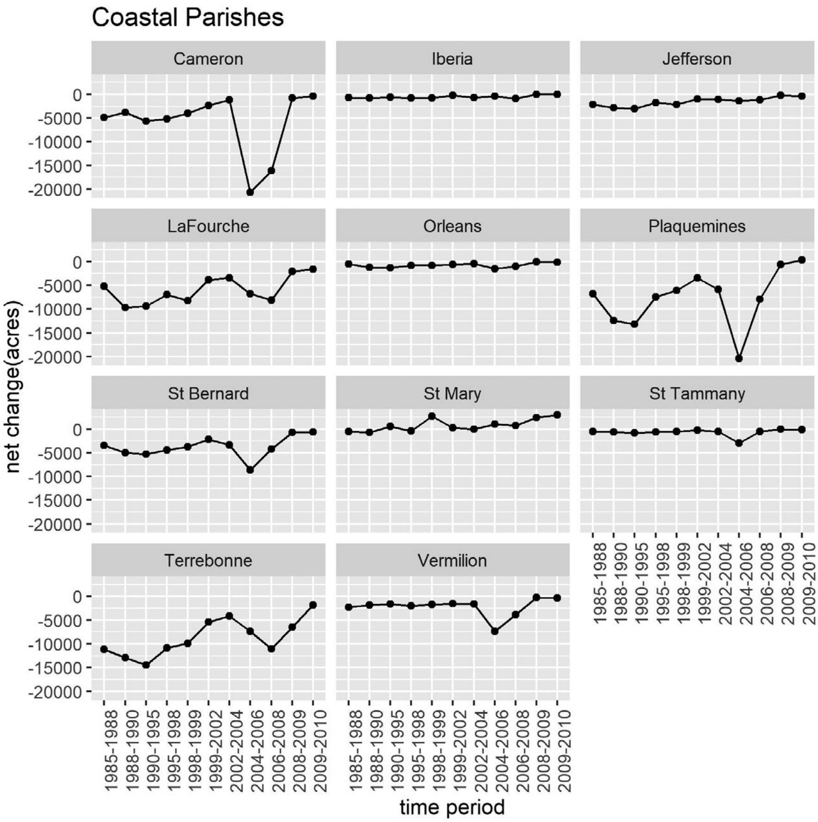

Figure 3 ■ Wetland loss over time for each of the coastal parishes.

The heterogeneity of wetland loss across space is best seen in looking at the individual coastal parishes, where just a few of the parishes showed clear periods of large wetland loss (i.e., Plaquemines, Terrebonne, and Cameron Parishes), while in the others, wetland extent remained consistent over time. The parishes showing the most loss are those affected by major hurricanes and/or sediment starvation due to the levee system. A similar trend can be seen at smaller scales as well.

Wetland loss and level of commercial engagement were generally not correlated—except for a weak negative correlation at the community scale, meaning at this scale more wetland loss (negative rho value) correlates with slightly more commercial engagement or increased fishing activity (see Figure 3). Neither was wetland loss correlated with change in commercial engagement, meaning that dynamics are not changing simultaneously. While most of the relationships showed no

Table 2 ■ Spearman correlations between wetland loss and commercial engagement

	Wetland loss ~ commercial engagement		Wetland loss ~ change in commercial engagement	
scale	**rho**	**p-value**	**rho**	**p-value**
local	–.094	.096	–.039	.531
community	–.292	5.01e-7**	–.049	.457
parish	–.221	.106	–.097	.531
watershed	–.067	.644	–.035	.832

$p<.05$ is considered significant and depicted with *
$p<.001$ highly significant and depicted with **

correlation, the fact that the measures of degree of correlation varied across the scales examined suggests that in some cases the choice of scale may be important to teasing out relationships between variables.

Looking at the correlations between wetland loss and landings of wetland-dependent species, the relationship is clearer: the more wetland loss, the more landings recorded. This relationship is part of what is observed with commercial engagement and wetland loss, but at every scale the relationship is statistically significant for at least two species (Table 2). While perhaps counterintuitive, this finding suggests edge effects, that is, wetland loss increases wetland edge, which in turn

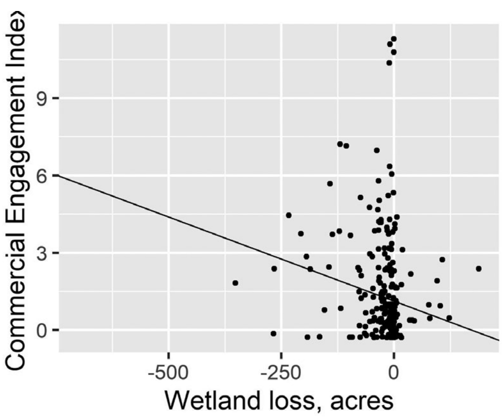

Figure 4 ■ Wetland loss is negatively correlated with commercial engagement at the community scale, but weakly. Rho values for the correlation are in the "community" row of Table 1.

Table 3 ■ Spearman correlations between wetland loss and landings of wetland-dependent species

	Blue crab		Northern brown shrimp		Eastern oysters	
scale	**rho**	**p-value**	**rho**	**p-value**	**rho**	**p-value**
local	−.258	4.25e-6**	−.230	7.919e-5**	−.337	8.454e-7**
community	−.265	5.26e-6**	−.356	1.38e-9**	−.196	.004*
parish	−.171	.171	−.460	.0010*	−.405	.008*
huc	−.545	5.725e-5**	−.569	2.27e-5**	−.631	8.801e-7**

$p < .05$ is considered significant and depicted with *
$p < .001$ highly significant and depicted with **

increases overall productivity in wetland-dependent species. For watersheds and parishes, the two large-scale categories defined by ecological versus social characteristics, the watersheds showed stronger effects for all three species.

Discussion of the Louisiana Case

The most consistent set of relationships is between wetland loss and landings of wetland-dependent species. However, we hypothesized that increased wetland loss would lead to fewer fish caught. Counterintuitively, the results show increased wetland loss is correlated with increased landings at most scales. This correlation is between wetland loss and total landings, not the change in landings, which is what might be expected. Numerous studies have examined this phenomenon in Louisiana wetlands and initially theorized that the cause was due to wetland loss leading to increasing wetland edge, which resulted in higher landings (Browder, Bartley et al. 1985; Browder, May et al. 1989; Rozas and Reed 1993; Zimmerman et al. 2002). However, more detailed studies have shown this relationship does not hold for all species. Instead, species' responses to wetland edge is variable and in some cases non-existent. Moreover, wetland loss in some areas of Louisiana has already surpassed the tipping point where wetland loss becomes great enough that wetland edge is also decreasing (Lewis et al. 2016). This dynamic creates a tension between short-term observations (fisheries are doing better with some wetland loss) and long-term likely outcomes (fisheries decrease when the tipping point is reached). This tension may create opposition to wetland restoration efforts aimed at avoiding the tipping point because the restoration could decrease or eliminate the short-term gains.

Commercial engagement is a composite indicator; so it is possible that at least some of the underlying components conflict in their relationship to wetland loss (landings, as shown above, contribute to the commercial engagement indicator). As a composite, commercial engagement is also troublesome because its creation through PCA makes it a relative indicator, allowing one to rank geographies against one another. However, if the whole region increases or decreases simultaneously, the relative position, and therefore commercial engagement indicator, will not change. Smaller-scale investigations may detect fishermen switching from one location to another as wetland loss progresses. This explains why the smallest scale commercial engagement indicators showed some correlation with wetland loss while larger scales did not.

Both commercial engagement and landings data may also be connected to wetland loss indirectly, through intervening variables. For example, the region, like most of the US, has seen a decrease in available fish houses and working waterfronts. Since these provide necessary infrastructure for the fishery and set prices for catch, they may be buffering slow changes in wetland cover until a tipping point occurs, such as property loss along the waterfront or business closures for financial reasons. Once the tipping point is crossed, then all the effects in aggregate will become apparent. Likewise, not all wetland types or locations equally contribute to the fishery; specifics of the type of wetland loss may determine fishery effects. Long-term monitoring data on these (or other possible) intervening variables is not currently available, but should be considered for further study.

The view from the larger scales exhibits a Simpson's paradox (Gardener 1979), where dynamics at the small scale are masked in aggregate. This is a type of Modifiable Areal Unit Problem (MAUP), where the choice of scale and resolution may bias results based on the spatial distribution of the underlying data (Ursache et al. 2021; Ripley 1981). In this case, the large scales show less variation through time, possibly because they may incorporate more of the fishermen's resilience mechanisms related to wetland loss, masking some of the smaller-scale dynamics. For example, as a result of losing a fishing spot due to wetland loss and therefore potential catch, a fisherman could (a) quit, (b) find a new spot, or (c) fish a new species. Finding a new spot within the scale of inquiry will not show up in the numbers. Finding a new species will not show up in commercial engagement values, if the species is found close to the same location (but would show up in species-specific landings, and may explain some of the increased landings in blue crabs and shrimp). This kind of switching is difficult to hide at the smallest scales, though trip ticket zones are potentially actually too small to incorporate the areas required for this resilience tactic.

In situations that scientists cannot directly experiment on or model in the laboratory, such as large-scale wetland loss, a statistical approach utilizing indicators is one of few available approaches. The theory behind a statistical approach is often grounded in smaller natural history or lab-based experiments that need to be tested on a larger scale. Yet, this approach comes with limitations, especially when looking at long-term time-series data. Monitoring programs are expensive to maintain, and therefore typically one type of data collection needs to serve the needs of the many research projects. Given this, here the basic indicators showed correlative relationships at a variety of scales. The whole story is best told from a variety of scales, and these statistical relationships can be used to tell the story at all scales, not just the ones for which we have good, detailed data.

In this case, available data did not yield many clear conclusions at a mid-range scale. The parish and watershed scales are both at the scale of human decision-making and fishery species ecology. The community scale is too small, and potentially not spatially resolute enough, to capture the dynamics between commercial fishery behavior and wetland loss. We attempted to model reach from a community by an hour's transit by fishing vessel from the community center, but captains may consider going farther in times of need or cooperate with businesses in neighboring communities in order to leverage resources. Similarly, some fishers report fishing out of more than one trip ticket zone in a day, so local trip ticket zone may be too small to capture human-scale decision-making. However, this statistical exercise helps to identify where the data gaps are in terms of spatial scale, and may direct future analyses to consider different ways of grouping individual fishing reports. For example, a community of practice or interest might make more sense than a place-based Census-defined community; this could be anchored around central infrastructure or people, for example, around individual dealers or working waterfronts or gear types (Clay and Olson 2008).

Conclusions from the Scale Discussion

The scale problem is actually a collection of multifaceted components that can be explored by asking clearly defined research questions. Often, this may lead to a polycentric approach to scale as in the Louisiana case, but researchers and managers should keep in mind the difficulty of shifting the scales of inquiry that are based on long-established management jurisdictions or significant long-standing ecological boundaries. While a careful consideration of the relationship among data, modeling, and management scales is an essential analytical best practice, one must accept that many research questions will have to tolerate an ambiguity of scale. Not every piece of information can be clearly scaled in a manner that fully incorporates place- or group-specific diversity. Testing models for their sensitivity across scales can help us to collectively improve how we integrate scalar data.

Any focus on human-environment interactions in a specific location also occurs in a broader global context that contributes external forces to the local relationship. These forces are often impossible to change, but instead set a context in which the interaction of interest occurs (Low et al. 1999). In the Louisiana case study, oil industry dynamics, global fisheries markets, and other global society dynamics may influence local fishing effort, which in turn affects landings. The many causes of wetland loss in the area may also affect the relationship between wetland loss and fisheries differently. For example, oil company canals provide easier access to the bayous that may otherwise have been difficult to fish, while sea level rise threatening fishers' houses may cause depopulation of the area and potentially decrease overall fishing pressure.

Most management-relevant questions rely on secondary data for at least one scale of inquiry. Ideally, scientists will then work with partners to identify priority areas for primary data collection that can be custom designed to the research questions within the limits of time and funding. The goal of this data integration is to provide the best available science, work to improve the quality and relevance of that science, and work with managers who are using the information to better communicate why the analysis occurred at a particular scale. For instance, Louisiana coastal managers make decisions at the state level, but would benefit from additional studies of wetland-fishery dynamics at the community or local scale to make fully informed decisions. Researchers and managers, in consultation with stakeholders, can decide together what datasets make sense to include in the analysis, what their limitations are, and what the tradeoffs are of using data of different scales, given management goals.

As noted by Natalie Small, Max Munday, and I. Durance (2017), scales of governance and social levels of organization rarely match the scales of ecological organization. Further, driving forces are dynamic and may vary over time and space, exacerbating the "problem of fit" between ecological and institutional interactions (Folke et al. 2007; Young 2002). Understanding implications of cross-scale interactions is crucial to determine whether secondary data collected at a given scale can be used to inform management decisions when the scale imperfectly matches the data. This is a much-needed area of future research attention. Nested management jurisdictions, such as are present in Louisiana (albeit, in a system sometimes described as complicated and confusingly complex), can help in the matching exercise. For example, the findings of small-scale relationships between wetland loss and fisheries catch could be discussed at the Louisiana Shrimp Task Force, and if it is a concern for multiple communities, be elevated to managers at the Louisiana Department of Fish and Wildlife (for shrimp), CPRA (for wetlands), or the Louisiana Trustee Implementation Group (for Gulf-wide concerns). This way, a small-scale phenomenon that may be masked in analyses at higher spatial scales can still be elevated to management bodies that function at that larger scale.

Determining how best to resolve scale mismatches may require a great deal of social learning (Cumming et al. 2006; Folke et al. 2007). Studies are needed that involve insights from stakeholders to align the scales of drivers, desired outcomes, and management solutions (Bellwood et al. 2019; Small et al. 2017). These kinds of studies are absolutely invaluable in making sure the conclusions from any given study that aspires to influence management are scalable to the spatial level where management decision-making occurs.

In the end, the implications of choosing a particular scale of inquiry should be made explicit in order to equitably evaluate the tradeoffs involved. Consider the implications of evaluating local-scale dynamics of fisheries based on an artificial reef or other fish aggregating device versus a region-wide assessment of fisheries that tracks changes arising from a slow, distributed loss of wetlands. Both kinds of spatial examinations have their place, as well as studies that investigate the relationship between local adaptation measures and regional landscape change, but the scale of study should be chosen to meet the needs of managers making decisions at the fixed scale of their jurisdiction. Virtually all resource management analyses are impacted by the decisions about scale made by analysts. This makes discussions and analyses of scales of critical importance and worthy of further investigation.

The authors are members of the Human Dimensions Working Group in the Integrated Ecosystem Assessment Program at the National Oceanic and Atmospheric Administration. They represent a variety of social science disciplines, including economics, sociology, geography, and anthropology, as well as geographic regions of the United States. The goal of the Human Dimensions Working Group is to ensure that human dimensions are considered in ecosystem-based fisheries management in the United States by contributing new methods and theories to relevant management councils.

Acknowledgments

This article was made possible by the NOAA Integrated Ecosystem Assessment Program and is a joint effort of the Human Dimensions Working Group and Gulf of Mexico regional team. Authors would like to thank three internal reviewers for their insights, especially on Louisiana culture: Terry McTigue. Shannon Martin, and Karma Norman. Government labor was provided by CSS, Inc under Contract No. EA133C-14-NC-1384.

Amy Freitag is a sociologist with NOAA's National Centers for Coastal Ocean Science. Email: amy.freitag@noaa.gov.

Suzana Blake is a research associate with the University of Miami CIMAS and an affiliate of NOAA's Southeast Fisheries Science Center.
Email: suzana.blake@noaa.gov.

Patricia M. Clay is an anthropologist with NOAA's Northeast Fisheries Science Center. Email: patricia.m.clay@noaa.gov.

Alan C. Haynie is an economist with NOAA's Alaska Fisheries Science Center. Email: alan.haynie@noaa.gov.

Chris Kelble is the Director of the Ocean Chemistry and Ecosystems Division at NOAA's Atlantic Oceanographic and Meteorological Laboratory.
Email: chris.kelble@noaa.gov.

Michael Jepson is the recently retired Social Science Branch Chief of SERO.

Stephen Kasperski is an economist with NOAA's Alaska Fisheries Science Center. Email: stephen.kasperski@noaa.gov.

Kirsten M. Leong is a social scientist with NOAA's Pacific Islands Fisheries Center. Email: kirsten.leong@noaa.gov.

Jamal H. Moss is a research fish biologist with the Alaska Fisheries Science Center. Email: jamal.moss@noaa.gov.

Seann D. Regan is a human geographer with NOAA's National Centers for Coastal Ocean Science. Email: seann.regan@noaa.gov.

Note

1. National Oceanic and Atmospheric Administration's National Marine Fisheries Service, "Social Indicators," dataset map. *NMFS, NOAA*. https://www.st.nmfs.noaa.gov/data-and-tools/social-indicators/ (accessed 25 March 2022).

References

Abbott, Joshua, and James Wilen. 2011. "Dissecting the Tragedy: A Spatial Model of Behavior in the Commons." *Journal of Environmental Economics and Management* 62 (3): 386–401.

Adger, W. Neil, and Cecilia Luttrell. 2000. "Property Rights and the Utilisation of Wetlands." *Ecological Economics* 35 (1): 75–89.

Apitz, Sabine E., Michael Elliott, Michelle Fountain, and Tamara S. Galloway. 2006. "European Environmental Management: Moving to an Ecosystem Approach." *Integrated Environmental Assessment and Management* 2 (1): 80–85.

Barnes, Stephen, Craig Bond, Nicholas Burger, Kate Anania, Aaron Strong, Sarah Weilant, and Stephanie Virgets. 2015. *Economic Valuation of Coastal Land Loss in Louisiana*. Baton Rouge: Coastal Protection and Restoration Authority of Louisiana.

Barra, Monica. 2016. "Natural Infrastructures: Sediment, Science, and the Future of Southeast Louisiana." *Engagement, a Blog of the Anthropology and Environment Society*, 22 March. https://aesengagement.wordpress.com/2016/03/22/natural-infrastructures-sediment-science-and-the-future-of-southeast-louisiana/.

Bellwood, David R., Morgan S. Pratchett, Tiffany H. Morrison, Georgina G. Gurney, Terry P. Hughes, Jorge G. Álvarez-Romero, Jon C. Day, Ruby Grantham, Alana Grecha, Andrew S. Hoeya, Geoffrey P. Jones, John M. Pandolfi, Sterling B. Tebbett, Erika Techera, Rebecca Weeks, and Graeme S. Cumming. 2019. "Coral Reef Conservation in the Anthropocene: Confronting Spatial Mismatches and Prioritizing Functions." *Biological Conservation* 23 (6): 604–615.

Boesch, Don, and R. Eugene Turner. 1984. "Dependence of Fishery Species on Salt Marshes: The Role of Food and Refuge." *Estuaries* 7 (4): 460–468.

Brookfield, Katherine, Tim Gray, and Jenny Hatchard. 2005. "The Concept of Fisheries-Dependent Communities: A Comparative Analysis of Four UK Case Studies:

Shetland, Peterhead, North Shields and Lowestoft." *Fisheries Research* 72 (1): 55–69.

Browder, Joan A., Henry A. Bartley, and Kevin S. Davis. 1985. "A Probabilistic Model of the Relationship between Marshland-Water Interface and Marsh Disintegration." *Ecological Modelling* 29 (1–4): 245–260.

Browder, Joan A., L. Nelson May, Jr., Alan Rosenthal, James G. Gosselink, and Robert H. Baumann. 1989. "Modeling Future Trends in Wetland Loss and Brown Shrimp Production in Louisiana Using Thematic Mapper Imagery." *Remote Sensing of Environment* 28: 45–59.

Cash, David W., W. Neil Adger, Fikret Berkes, Po Garden, Louis Lebel, Per Olsson, Lowell Pritchard, and Oran Young. 2006. "Scale and Cross-Scale Dynamics: Governance and Information in a Multilevel World." *Ecology and Society* 11 (2). http://www.ecologyandsociety.org/vol11/iss2/art8/

Chesney, Edward J., Donald M. Baltz, and R. Glenn Thomas. 2000. "Louisiana Estuarine and Coastal Fisheries and Habitats: Perspectives from a Fish's Eye View." *Ecological Applications* 10 (2): 350–366.

Cheung, William, Elizabeth McLeod, Fiorenza Micheli, and Colette Wabnitz. 2018. ECCWO-4 Workshop on "Exploring Potential Ocean-Based Solutions to Climate Change Impacts on Marine Biodiversity and Ecosystem Services." *PICES Press* 26 (2): 43–44.

Clay, Patricia, and Julia Olson. 2008. "Defining 'Fishing Communities': Vulnerability and the Magnuson-Stevens Fishery Conservation and Management Act." *Human Ecology Review* 15 (2): 143–160.

Coastal Protection and Restoration Authority of Louisiana. 2017. "Louisiana's Comprehensive Master Plan for a Sustainable Coast." https://coastal.la.gov/our-plan/2017-coastal-master-plan/ (accessed 26 March 2022).

Condrey, Richard, Paul Kemp, Jenneke Visser, James Gosselink, Dianne Lindstedt, Earl Melancon, Jr., Gary Peterson, Bruce Thompson. 1995. *Status, Trends, and Possible Causes of Change in Living Resources in the Barataria and Terrebonne Estuarine Systems*. Thibodaux, LA: Barataria-Terrebonne National Estuary Program.

Couvillion, Brady R., John A. Barras, Gregory D. Steyer, William Sleavin, Michelle Fischer, Holly Beck, Nadine Trahan, Brad Griffin, and David Heckman. 2011. *Land Area Change in Coastal Louisiana from 1932 to 2010*. Reston, VA: US Geological Survey. https://pubs.usgs.gov/sim/3164/downloads/SIM3164_Pamphlet.pdf.

Cowan, James H., and R. Eugene Turner. 1988. "Modeling Wetland Loss in Coastal Louisiana: Geology, Geography, and Human Modifications." *Environmental Management* 12 (6): 827–838.

Cumming, Graeme S., David H. M. Cumming, and Charles L. Redman. 2006. "Scale Mismatches in Social-Ecological Systems: Causes, Consequences, and Solutions." *Ecology and Society* 11 (1): http://www.ecologyandsociety.org/vol11/iss1/art14.

Dinda, Soumyananda. 2004. "Environmental Kuznets Curve Hypothesis: A Survey." *Ecological Economics* 49 (4): 431–455.

Duraiappah, Anantha Kumar, Stanley Tanyi Asah, Eduardo S. Brondizio, Nicolas Kosoy, Patrick J. O'Farrell, Anne-Helene Prieur-Richard, Suneetha M. Subramanian, and Kazuhiko Takeuchi. 2014. "Managing the Mismatches to Provide Ecosystem Services for Human Well-Being: A Conceptual Framework for Understanding the New Commons." *Current Opinion in Environmental Sustainability* 7: 94–100.

Engle, Virginia. 2011. "Estimating the Provision of Ecosystem Services by Gulf of Mexico Coastal Wetlands." *Wetlands* 31 (1): 179–193.

Folke, Carl, Lowell Pritchard Jr., Fikret Berkes, Johan Colding, and Uno Svedin. 2007. "The Problem of Fit between Ecosystems and Institutions: Ten Years Later." *Ecology and Society* 12 (1): http://www.ecologyandsociety.org/vol12/iss1/art30.

Gardener, Martin. 1979. "Mathematical Games: On the Fabric of Inductive Logic, and Some Probability Paradoxes." *Scientific American* 234 (3): 119–124.

Gallagher, Kevin P., and Strom C. Thacker. 2008. "Democracy, income, and environmental quality." *PERI Working Papers*: 124.

Grêt-Regamey, Adrienne, Bettina Weibel, Kenneth J. Bagstad, Marika Ferrari, Davide Geneletti, Hermann Klug, Uta Schirpke, and Ulrike Tappeiner. 2014. "On the Effects of Scale for Ecosystem Services Mapping." *PLoS One* 9 (12): e112601.

Harvey, Chris J., Christopher R. Kelble, and Franklin B. Schwing. 2017. "Implementing 'The IEA': Using Integrated Ecosystem Assessment Frameworks, Programs, and Applications in Support of Operationalizing Ecosystem-based Management." *ICES Journal of Marine Science* 74 (1): 398–405.

Hattama, Caroline, Jonathan P. Atkins, Nicola Beaumont, Tobias Börger, Anne Böhnke-Henrichs, Daryl Burdon, Rudolf deGroot, Ellen Hoefnagel, Paulo A. L. D. Nunes, Joanna Piwowarczyk, Sergio Sastre, and Melanie C. Austen. 2015. "Marine Ecosystem Services: Linking Indicators to their Classification." *Ecological Indicators* 49: 61–75.

Hausmann, Anna, R. O. B. Slotow, Jonathan K. Burns, and Enrico Di Minin. 2016. "The Ecosystem Service of Sense of Place: Benefits for Human Well-Being and Biodiversity Conservation." *Environmental Conservation* 43 (2): 117–127.

Havice, Elizabeth, Lisa M. Campbell, and Amy Braun. 2018. "Science, Scale and the Frontier of Governing Mobile Marine Species." *International Social Science Journal* 68 (229–230): 273–289.

Hicks, Christina C., Larry B. Crowder, Nicholas AJ Graham, John N. Kittinger, and Elodie Le Cornu. 2016. "Social Drivers Forewarn of Marine Regime Shifts." *Frontiers in Ecology and the Environment* 14 (5): 252–260.

Hotelling, Harold. 1929. "Stability in Competition." *Journal of Economics* 41 (10): 50–63.

Jennings, Simon, Michel Kaiser, and John D. Reynolds. 2009. *Marine Fisheries Ecology*. New York: John Wiley & Sons.

Jepson, Michael, and Lisa Colburn. 2013. *Development of Social Indicators of Fishing Community Vulnerability and Resilience in the U.S. Southeast and Northeast Regions, NOAA, US Department of Commerce*. https://repository.library.noaa.gov/view/noaa/4438 (accessed 25 March 2022).

Jordan, Steven J., Timothy O'Higgins, and John A. Dittmar. 2012. "Ecosystem Services of Coastal Habitats and Fisheries: Multiscale Ecological and Economic Models in Support of Ecosystem-Based Management." *Marine and Coastal Fisheries* 4 (1): 573–586.

Krugman, Paul, and Anthony Venables. 1995. "The Seamless World: A Spatial Model of International Specialization. *National Bureau of Economic Research*, Working paper 5220, August 1995. https://doi.org/10.3386/w5220.

Lazzari, Natali, Mikel A. Becerro, Jose A. Sanabria-Fernandez, and Berta Martin-Lopez. 2019. "Spatial Characterization of Coastal Marine Social-Ecological Systems: Insights for Integrated Management." *Environmental Science and Policy* 92: 56–65.

Leong, Kirsten M., Supin Wongbusarakum, Rebecca J. Ingram, Alexander Mawyer, and Melissa Poe. 2019. "Improving Representation of Human Well-Being and Cultural Importance in Conceptualizing the West Hawai'i Ecosystem." *Frontiers in Marine Science* 6. doi: https://doi.org/10.3389/fmars.2019.00231.

Levin, Phillip S., Michael J. Fogarty, Steven A. Murawski, and David Fluharty. 2009. "Integrated Ecosystem Assessments: Developing the Scientific Basis for Ecosystem-Based Management of the Ocean." *PLoS Biology* 7 (1): e1000014.

Lewis, Kristy A., Kim de Mutsert, Jeroen Steenbeek, H. Peele, James H. Cowan Jr., and Joe Buszowski. 2016. "Employing Ecosystem Models and Geographic Information Systems (GIS) to Investigate the Response of Changing Marsh Edge on Historical Biomass of Estuarine Nekton in Barataria Bay, Louisiana, USA." *Ecological Modelling* 331: 129–141.

Low, Bobbi, Robert Costanza, Elinor Ostrom, James Wilson, and Carl P. Simon. 1999. "Human-Ecosystem Interactions: A Dynamic Integrated Model." *Ecological Economics* 31 (2): 227–242.

Maldonado, Julie. 2014. "A Multiple Knowledge Approach for Adaptation to Environmental Change: Lessons Learned from Coastal Louisiana's Tribal Communities." *Journal of Political Ecology* 21 (1): 61–82.

Martin-Lopez, Berta, Maria R. Felipe-Lucia, Elena M. Bennett, Albert Norstrom, Garry Peterson, Tobias Plieninger, Christina C. Hicks, Francis Turkelboom, Marina Garcia-Llorente, Sander Jacobs, Sandra Lavorel, and Bruno Locatelli. 2019. "A Novel Telecoupling Framework to Assess Social Relations across Spatial Scales for Ecosystem Services Research." *Journal of Environmental Management* 241: 251–263.

Masterson, Vanessa A., Richard C. Stedman, Johan Enqvist, Maria Tengö, Matteo Giusti, Darin Wahl, and Uno Svedin. 2017. "The Contribution of Sense of Place to Social-ecological Systems Research: A Review and Research Agenda." *Ecology and Society* 22 (1): https://doi.org/10.5751/ ES-08872-220149.

Mederer, Helen J. 1999. "Surviving the Demise of a Way of Life: Stress and Resilience in Northeastern Commercial Fishing Families." In *The Dynamics of Resilient Families,* 135–163. Thousand Oaks, CA: Sage.

Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-Being: Synthesis.* Washington, DC: Island Press.

Minello, Thomas J., Kenneth W. Able, Michael P. Weinstein, and Cynthia G Hays. 2003. "Salt Marshes as Nurseries for Nekton: Testing Hypotheses on Density, Growth and Survival through Meta-analysis." *Marine Ecology Progress Series* 246: 39–59. https://www.int-res.com/abstracts/meps/v246/p39-59/ (accessed 25 March 2022).

Moore, Adam. 2008. "Rethinking Scale as a Geographical Category: From Analysis to Practice." *Progress in Human Geography* 32 (2): 203–225.

Neumann, Roderick. 2009. "Political Ecology: Theorizing Scale." *Progress in Human Geography* 33 (3): 398–406.

NOAA Fisheries. 2016. *NOAA Fisheries Ecosystem-Based Fisheries System Roadmap.* https://media.fisheries.noaa.gov/dam-migration/01-120-01.pdf

O'Farrell, Shay, James N. Sanchirico, Orr Spiegel, Maxime Depalle, Alan C. Haynie, Steven Murawski, Larry Perruso, and Andrew Strelcheck. 2019. "Disturbance Modifies Payoffs in the Explore-Exploit Trade-off." *Nature Communications* 10 (1): 1–9.

O'Higgins, Tim, Antonio A. Nogueira, and Ana I. Lillebø. 2019. "A Simple Spatial Typology for Assessment of Complex Coastal Ecosystem Services across Multiple Scales." *Science of the Total Environment* 649: 1452–1466.

Okamoto, Daniel K., Melissa R. Poe, Tessa B. Francis, Andre E. Punt, Phillip S. Levin, Andrew O. Shelton, Derek R. Armitage, Jaclyn S. Cleary, Sherri C. Dressell, Russ Jones, Harvey Kitka, Lynn C. Lee, Alec D. MacCall, Jim A. McIsaac, Steve Reifenstuhl, Jennifer J. Silver, Jorn O. Schmidt, Thomas F. Thornton, Rudiger Voss, and John Woodruff. 2020. "Attending to Spatial Social-ecological Sensitivities to Improve Trade-Off Analysis in Natural Resource Management." *Fish and Fisheries* 21 (1): 1–12.

Raudsepp-Hearne, Ciara, and Garry D. Peterson. 2016. "Scale and Ecosystem Services: How Do Observation, Management, and Analysis Shift with Scale—Lessons from Québec." *Ecology and Society* 21 (3): https://www.ecologyandsociety.org/vol21/iss3/art16/ .

Ripley, Brian D. 1981. *Spatial Statistics*. New York: John Wiley & Sons.

Rocha, Juan, Garry Peterson, Orjan Bodin, and Simon Levin. 2018. "Cascading Regime Shifts within and across Scales." *Science* 362 (6421): 1379–1383.

Royal Engineers and Consultants, LLC, and Earth Economics. 2016. *Basinwide Socioeconomic Analysis of Four Proposed Sediment Diversions: Final Report to the Louisiana Coastal Protection and Restoration Authority in Fulfillment of Task 3.5 of the Scope of Work.*.

Roy, Samapriya, Scott M. Robeson, Alejandra C. Ortiz, and Douglas A. Edmonds. 2020. "Spatial and Temporal Patterns of Land Loss in the Lower Mississippi River Delta from 1983 to 2016." *Remote Sensing of Environment* 250: 112046. https://doi.org/10.1016/j.rse.2020.112046.

Rozas, Lawrence, and Denise J. Reed. 1993. "Nekton use of Marsh-Surface Habitats in Louisiana (USA) Deltaic Salt Marshes Undergoing Submergence." *Marine Ecology Progress Series* 96: 147.

Samhouri, Jamal F., Kelly S. Andrews, Gavin Fay, Chris J. Harvey, Elliott L. Hazen, Shannon M. Hennessey, Kirstin Holsman, Mary E. Hunsicker, Scott I. Large, Kristin N. Marshall, Adrian C. Stier, Jamie C. Tam, and Stephanie G. Zador. 2017. "Defining Ecosystem Thresholds for Human Activities and Environmental Pressures in the California Current." *Ecosphere* 8 (6):https://doi.org/10.1002/ecs2.1860 .

Silver, Jennifer. 2008. "Weighing in on Scale: Synthesizing Disciplinary Approaches to Scale in the Context of Building Interdisciplinary Resource Management." *Society and Natural Resources* 21(10): 921–929.

Small, Natalie, Max Munday, and I. Durance. 2017. "The Challenge of Valuing Ecosystem Services that Have No Material Benefits." *Global Environmental Change* 44: 57–67.

Sowman, Merle, and Jackie Sunde. 2018. "Social Impacts of Marine Protected Areas in South Africa on Coastal Fishing Communities." *Ocean & Coastal Management* 157: 168–179.

Stern, David I. 2004. "The Rise and Fall of the Environmental Kuznets Curve." *World Development* 32 (8): 1419–1439.

Stern, David I. 2018. "The Environmental Kuznets Curve, Reference Module in Earth Systems and Environmental Sciences." *Elsevier*. https://doi.org/10.1016/B978-0-12-409548-9.09278-2.

Tsurumi, Tetsuya, and Shunsuke Managi. 2010. "Decomposition of the Environmental Kuznets Curve: Scale, Technique, and Composition Effects." *Environmental Economics and Policy Studies* 11 (1–4): 19–36.

Turner, R. Eugene, and Donald F. Boesch. 1988. "Aquatic Animal Production and Wetland Relationships: Insights Gleaned Following Wetland Loss or Gain." In *The Ecology and Management of Wetlands,* 25–39. New York: Springer.

Ursache, Alexandra, Seann Regan, Allison De Marco, Dustin T. Duncan, and The Family Life Project Key Investigators. 2021. "Measuring Neighborhood Deprivation for Childhood Health and Development: Scale Implications in Rural and Urban Context." *Geospatial Health* 16 (1). https://doi.org/10.4081/gh.2021.926.

US Geological Survey. 2019. *National Hydrography Dataset*. https://www.usgs.gov/national-hydrography/access-national-hydrography-products

Van Ginkel, Rob. 2001. "Inshore Fishermen: Cultural Dimensions of a Maritime Occupation." In *Inshore Fisheries Management,* 177–193. Dordrecht: Springer.

Watson, Jordan T., Alan C. Haynie, Patrick J. Sullivan, Larry Perruso, Shay O'Farrell, James N. Sanchirico, and Franz J. Mueter. 2018. "Vessel Monitoring Systems (VMS) Reveal an Increase in Fishing Efficiency Following Regulatory Changes in a Demersal Longline Fishery." *Fisheries Research* 207: 85–94.

Wyborn, Carina. 2015. "Cross-Scale Linkages in Connectivity Conservation: Adaptive Governance Challenges in Spatially Distributed Networks." *Environmental Policy and Governance* 25 (1): 1–15.

Young, Oran R. 2002. *The Institutional Dimensions of Environmental Change: Fit, Interplay and Scale*. Cambridge, MA: MIT Press.

Zimmerman, Roger, Thomas J. Minello, and Lawrence P. Rozas. 2002. "Salt Marsh Linkages to Productivity of Penaeid Shrimps and Blue Crabs in the Northern Gulf of Mexico." In *Concepts and Controversies in Tidal Marsh Ecology,* 293–314. Dordrecht: Springer.