The Vexing Problem of Defining a “Fishery”

Emma Fuller, Jameal Samhouri, …?

**INTRODUCTION**

Fisheries management is composed of two idealized units: stocks and fisheries. An understanding of stock dynamics is required for appropriate harvest regulations to be set, and a fishery is analogous: a discrete group of vessels targeting the same stocks using the same gear, in the same area. However while stock identification is a process with well-developed methods, the definition of a fishery remains much less well defined.

Early work on fishery definitions was motivated by the difficulty of matching single species management quota to multi-species fisheries (Murawski et al. 1983). Definitions of fisheries which caught multiple species offered an alternative where managers could specify quota for a collection of stocks commonly harvested together. These approaches often defined fisheries not only by the catch composition and gear, but by the area and time of year (commonly month). With fisheries defined by month, area, gear, and species, definitions of a fishery matched the levers management was able to pull to constrain harvest. However these types of quantitative definitions are only patchily available: European fisheries, especially in the bay of Biscay where some of the earliest examples of these analyses exist, are often fairly well covered. The Baltic, and even the US Northeast all have examples of such analyses. However the US West Coast commercial fisheries, one of the most speciose set of commercial fisheries in the US, remains unexamined.

Here, we provide a low-constraint method of classifying fisheries for large spatial and temporal scales updated to take advantage of recent advances in clustering algorithms and computing power developed a novel classification. We use this classification to: (i) calculate vessel-level participation in individual fisheries in the California Current and (ii) determine emergent diversification of a vessel’s revenue and participation across fisheries. We found that the majority of vessels examined were generalists, defined as those participating in, and receiving most of their revenue from more than one commercial fishery.

**METHODS**

**Description of Data Sources**

We collected vessel landings tickets for all commercial landings on the US west-coast between 2006-2014 from the Pacific Fisheries Information Network (PacFIN) database ([www.psmfc.org](http://www.psmfc.org/)). These data record the landing of 2.7 million metric tons of 232 different species, landed over the course of over a million trips from Washington to California, by over six thousand different vessels for a combined value of approximately $4 billion (adjusted for 2009 inflation).

**Defining Realized Fisheries**

We define fisheries as harvest assemblages caught with a specific gear (van Putten et al. 2012; Boonstra and Hentati Sundberg 2014). To calculate the similarity between pairs of trips we compare trips’ revenue profiles, or the amounts of money each species returns in a given landing. To compute the similarity between the trips’ revenue profiles we calculate the Hellinger distance *D* (P. Legendre and Legendre 2012). This distance metric has the benefit that it is asymmetric, where the presence of a species in both trips is considered more informative than the absence of a species. The Hellinger distance between the species composition of two fishing trips *A* and *B* is defined as

|  |  |
| --- | --- |
|  | (1) |

where *ai* is the fraction of revenue derived from species *i* on trip *A*, *bi* is the fraction of revenue derived from species *i* on trip *B*, and *S* indicates the total number of species collected in both trips. With this metric, trips *A* and *B* become increasingly similar (and the Hellinger distance declines) as the proportion of revenue attributable to each of the *S* species becomes increasingly matched. Using these pairwise distances we build a distance matrix.

We identified realized fisheries as groups of trips with similar target assemblages using the infoMap community detection algorithm (Rosvall and Bergstrom 2008). This algorithm examines networks for subgraphs more interconnected to one another than the network in which it is embedded. To generate the required network we transformed the distance matrix into a similarity matrix by subtracting the distance metric’s upper limit (i.e. ) from each pairwise distance. The result is a weighted, undirected network where trips are connected by edges proportional to their similarity. However, because our dataset contained over one million unique trips, it was computationally intractable for us to perform clustering using a single matrix containing all pairwise similarities. To obtain manageable matrix sizes we used one year of landings (2010) which we split by gear. Pairwise distances among trips and community detection were calculated within each gear partition, which grouped trips into target assemblage categories. To classify the 2006-2009, 2012-2014 trips to fisheries, we assigned each unclassified trip to the same realized fishery as the 2010 trip to which it was closest in multi-dimensional space using a k-nearest neighbors algorithm.

A challenge in testing the effectiveness of this classification method, and part of the reason for its need, is that there is not an independent classification of US west coast fisheries that we could use to compare the results. To address this issue, we tested the reliability of our classification approach by evaluating the extent to which it identified known spatial and temporal structure of well-described US West Coast fisheries and fishery sectors. Specifically, because we did not bound our clusters spatially, temporally, or by vessel characteristics, we were able to compare our emergent realized fisheries to existing sector definitions of groundfish, and groundfish impacting fisheries provided by the Northwest Fisheries Science Center Observer Program (Northwest Fisheries Science Center 2015).

**RESULTS**

Applied to the landing ticket data, our clustering algorithm identified 118 realized fisheries (Appendix, Table 1). Realized fisheries often consisted of a single species, but could also comprise assemblages of species (Fig. 2b). Whether their catch consisted of a single species or multiple species, the realized fisheries were characterized by distinct temporal and spatial structure (Fig. 3). This structure showed strong agreement with the NWFSC Observer sector designations, as did comparisons of vessel sizes and catch composition (single- vs. multi-species, Table 1).

The realized fisheries varied by several orders of magnitude in effort (number of trips) and revenue (Fig. 2b), with a small number of fisheries accounting for the majority of effort and revenue. For example, only 15 of the 118 fisheries were responsible for 90% of ex-vessel revenue and landings (pounds) in the time period we examined (Table 1). These key realized fisheries included sectors which have been well-studied, but not quantitatively described prior to now, for example the Dungeness crab pot (Botsford and Wickham 1978), spiny lobster pot (Kay et al. 2012), and red urchin diving (Smith and Wilen 2003) (Table 1) realized fisheries.

**DISCUSSION**

Most previous approaches to quantitatively define a fishery using effort data are highly constrained. The constraints are typically spatial (i.e. blocking the seascape into statistical areas (ref) or temporal (examining trends in catch assemblage by month). Instead of these constraints, we use species composition and gear. The spatial and temporal structure then becomes emergent from the data, rather than applied a priori.

These patterns in space and time reflect the qualitative patterns described in many of these fisheries. Pink shrimp fishery, for example, has been growing over the last 10 years, and this increase in participation is visible (Fig 3a). Similarly can see the drop in chinook, due in part to the 2008-2009 closures. Dover sole roller trawl shows a marked change before and after 2011 when catch shares were implemented.

By classifying fisheries simultaneous offers a robust way to be able to study dynamics of multiple fisheries simultaneously. It’s well known that fishermen participate in multiple fisheries throughout the year, despite the fact that most studies examine the dynamics of a single fishery.

**Acknowledgements**

EF acknowledges NSF for funding (GRFP, CNHXX)

**References**

Anderson, James L, Christopher M Anderson, Jingjie Chu, Jennifer Meredith, Frank Asche, Gil Sylvia, Martin D Smith, et al. 2015. “The Fishery Performance Indicators: a Management Tool for Triple Bottom Line Outcomes.” Edited by George Tserpes. *PloS One* 10 (5): e0122809–20. doi:10.1371/journal.pone.0122809.

Boonstra, Wiebren J, and Jonas Hentati Sundberg. 2014. “Classifying Fishers' Behaviour. an Invitation to Fishing Styles.” *Fish and Fisheries* 17 (1): 78–100. doi:10.1111/faf.12092.

Botsford, Louis W, and Daniel E Wickham. 1978. “Behavior of Age-Specific, Density-Dependent Models and the Northern California Dungeness Crab ( Cancer Magister) Fishery.” *Journal of the Fisheries Research Board of Canada* 35 (6): 833–43. doi:10.1139/f78-134.

Brashares, Justin S, Peter Arcese, Moses K Sam, Peter B Coppolillo, A R E Sinclair, and Andrew Balmford. 2004. “Bushmeat Hunting, Wildlife Declines, and Fish Supply in West Africa.” *Science (New York, N.Y.)* 306 (5699). American Association for the Advancement of Science: 1180–83. doi:10.1126/science.1102425.

Field, John C. 2004. “Application of Ecosystem-Based Fishery Management Approaches in the Northern California Current .” Edited by Robert C Francis.

Hentati-Sundberg, J, J Hjelm, W J Boonstra, and H Österblom. 2014. “Management Forcing Increased Specialization in a Fishery System.” *Ecosystems* 18 (1). Springer US: 45–61. doi:10.1007/s10021-014-9811-3.

Jost, Lou. 2006. “Entropy and Diversity.” *Oikos* 113 (2): 363–75.

Kasperski, S, and D S Holland. 2013. “Income Diversification and Risk for Fishermen.” *Proceedings of the National Academy of Sciences*. doi:10.1073/pnas.1212278110/-/DCSupplemental.

Kay, Matthew C, Hunter S Lenihan, Carla M Guenther, Jono R Wilson, Christopher J Miller, and Samuel W Shrout. 2012. “Collaborative Assessment of California Spiny Lobster Population and Fishery Responses to a Marine Reserve Network..” *Ecological Applications : a Publication of the Ecological Society of America* 22 (1): 322–35.

Lade, Steven J, Susa Niiranen, Jonas Hentati Sundberg, Thorsten Blenckner, Wiebren J Boonstra, Kirill Orach, Martin F Quaas, Henrik Österblom, and Maja Schlüter. 2015. “An Empirical Model of the Baltic Sea Reveals the Importance of Social Dynamics for Ecological Regime Shifts..” *Proceedings of the National Academy of Sciences of the United States of America* 112 (35): 11120–25. doi:10.1073/pnas.1504954112.

Legendre, P, and L Legendre. 2012. *Numerical Ecology*. Elsevier.

Murawski, S A, A M Lange, M P Sissenwine, and R K Mayo. 1983. “Definition and Analysis of Multispecies Otter-Trawl Fisheries Off the Northeast Coast of the United States.” *ICES Journal of Marine Science* 41 (1). Oxford University Press: 13–27. doi:10.1093/icesjms/41.1.13.

Northwest Fisheries Science Center. 2015. “Data Analysis and Products.” *Fisheries Observation Science*. Seattle, WA. Accessed December 8. http://www.nwfsc.noaa.gov/research/divisions/fram/observation/data\_products/bottom\_trawl.cfm#description.

Opaluch, J J, and N E Bockstael. 1984. “Behavioral Modeling and Fisheries Management.” *Marine Resource Economics*. doi:10.2307/42628847.

Rosvall, Martin, and Carl T Bergstrom. 2008. “Maps of Random Walks on Complex Networks Reveal Community Structure.” *Proceedings of the National Academy of Sciences* 105 (4). National Acad Sciences: 1118–23. doi:10.1073/pnas.0706851105.

Sethi, S A, M Reimer, and G Knapp. 2014. “Alaskan Fishing Community Revenues and the Stabilizing Role of Fishing Portfolios.” *Marine Policy*. doi:10.1016/j.marpol.2014.03.027.

Smith, Martin D, and James E Wilen. 2003. “Economic Impacts of Marine Reserves: the Importance of Spatial Behavior.” *Journal of Environmental Economics and Management* 46 (2): 183–206. doi:10.1016/S0095-0696(03)00024-X.

Steneck, R S, T P Hughes, J E CINNER, W N ADGER, S N ARNOLD, F BERKES, S A BOUDREAU, et al. 2011. “Creation of a Gilded Trap by the High Economic Value of the Maine Lobster Fishery.” *Conservation Biology* 25 (5): 904–12. doi:10.1111/j.1523-1739.2011.01717.x.

van Putten, Ingrid E, Soile Kulmala, Olivier Thébaud, Natalie Dowling, Katell G Hamon, Trevor Hutton, and Sean Pascoe. 2012. “Theories and Behavioural Drivers Underlying Fleet Dynamics Models.” *Fish and Fisheries* 13 (2): 216–35. doi:10.1111/j.1467-2979.2011.00430.x.