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Connecting subsistence harvest and marine ecology: A cluster analysis of communities by fishing and hunting patterns

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ABSTRACT

Alaska Native subsistence hunters and fishers are engaged in environmental sampling, influenced by harvest technology and cultural preferences as well as biogeographical factors. We compared subsistence harvest patterns in 35 communities along the Bering, Chukchi, and Beaufort coasts of Alaska to identify affinities and groupings, and to compare those results with previous ecological analyses done for the same region. We used hierarchical cluster analysis to reveal spatial patterns in subsistence harvest records of coastal Alaska Native villages from the southern Bering Sea to the Beaufort Sea. Three main clusters were identified, correlating strongly with geography. The main division separates coastal villages of western Alaska from arctic villages along the northern Chukchi and Beaufort Seas and on islands of the Bering Sea. K-means groupings corroborate this result, with some differences. The second node splits the arctic villages, along the Chukchi, Beaufort and northern Bering Seas, where marine mammals dominate the harvest, from those on islands of the Bering Sea, characterized by seabird and seal harvests. These patterns closely resemble eco-regions proposed on biological grounds. Biogeography thus appears to be a significant factor in groupings by harvest characteristics, suggesting that subsistence harvests are a viable form of ecosystem sampling.

1. Introduction

Subsistence hunting and fishing account for a large proportion of the food produced and consumed in rural Alaska (ADF&G, 2012). The types of fish, marine mammals, seabirds, invertebrates, and plants that are harvested reflect cultural preferences, access, harvest technology, and of course the underlying ecology of the surrounding land, freshwaters, and sea (e.g., Wolfe, 2004). In effect, we attempt to use subsistence harvests as a means of sampling the local environment, acknowledging that hunting and fishing practices depend on more than just the presence of potential prey species and that the existence of a potential prey species does not necessarily mean it will be harvested. Analyzing and comparing community-level harvests offered the prospect of insights into biogeographical patterns. By comparing our analysis to previous analyses done on the available fish and seabird fauna, we also hoped to be able to assess the degree to which cultural or other factors further influence subsistence harvest patterns, by identifying any anomalies that could not be explained by biogeographical factors.

The biogeographical contribution is implied in various regional characterizations of subsistence hunting in Alaska, for example showing that marine mammals are the largest category by weight of harvest in the region of the state designated as Arctic by the Alaska Department of Fish and Game (ADF&G), whereas fish occupy the top spot in all other regions of the state (Huntington et al., 1998). The reason for this difference is readily apparent. Bowhead whales (*Balaena mysticetus*), for example, occur and are harvested only in the Arctic, and Pacific walrus (*Odobenus rosmarus divergens*) are only taken in small numbers in southwestern Alaska in contrast to harvests of several hundred animals per year in several arctic communities (ADF&G, N.D.). A more detailed look at regional and community harvest patterns, however, has not previously been undertaken.

Although aspects of the ecology of subsistence harvests and similar local uses of plants and animals have been examined in depth in many parts of the world (e.g., Smith and Winterhalder, 1981; Hurtado and Hill, 1987; Smith, 1991; Lauer and Aswani, 2008), we are unaware of any studies that have looked at regional patterns. Here we use cluster analysis of the harvest patterns of Alaska Native communities to identify patterns across communities and regions.

We use subsistence harvest data from 35 Aleut, Yup'ik, St. Lawrence Island Yupik, and Iñupiaq communities on the coasts and islands of the Bering, Chukchi, and Beaufort Seas. First we

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analyze subsistence harvests on a community level, using all harvested species in the analysis.

We next compare regional affinities for eco-regions defined by Sigler et al. (2011) for similar analyses of data for small zooplankton, large zooplankton, bottom fish, surface fish, and seabirds in the southern Bering, central Bering, northern Bering, Chukchi, and Beaufort seas.

2. Methods

Harvest data were compiled from the ADF&G Community Subsistence Information System database (ADF&G, N.D.a), available online, which contains the results of the vast majority of the comprehensive subsistence harvest surveys conducted by the Department's Division of Subsistence since 1980. Methods for gathering these data are available from ADF&G, especially in the Division of Subsistence Technical Paper series (ADF&G, N.D.b), where most results were first reported. First, we identified the communities in the database that are located on or within a few kilometers of the coast of the Bering, Chukchi, or Beaufort Sea. Second, we examined all records for each community, identifying those that reported harvest results for all species. (Many records examined only a particular species or class, such as migratory birds, herring *Clupea pallasii*, or marine mammals.) Then, we extracted the harvest data, expressed as kg of prey species harvested per resident, for each of the communities and years for which the full records were available.

The available data (Table 1) included 35 communities with a total of 53 harvest survey years, spanning the period 1964–2007 (more recent results are not yet in the database), plus subsistence harvest surveys conducted in Akutan, Emmonak, and Togiak for the year 2008 and in Savoonga for the year 2009 (Bering Sea Project Data Archive, N.D.) as part of the Bering Sea Project (Wiese et al., 2012). For communities with more than one year reported, we took an average of the harvest for each species reported. While much of the harvest data is specific to species, most surveys also include some records only identified to higher taxonomic groups. To apply the same standards across sites, we aggregated harvest data to the smallest available common taxonomic group (see supplementary data).

We recognize that results spanning 45 years may also span considerable environmental change in the region (e.g., Mueter and Litzow, 2008; Hunt et al., 2011), along with changes in subsistence patterns due to cultural and social factors. For example, the harvest of ringed seals in Kivalina dropped by an order of magnitude from the two surveys in the 1960s to the four surveys done between 1982 and 2007. A likely factor is the replacement of dog teams by snowmachines as the primary means of winter transportation. The harvest of no other species shows such a clear pattern of directional change over time, which leads us to conclude that the basic patterns in each community appear reasonably consistent over time, even if the total harvest has changed (comparison of other data from Kivalina from 1964, 1965, 1982, 1983, 1992, and 2007; Fall et al., 2013). Unfortunately, there are too few communities in which harvest surveys have been repeated to allow a detailed analysis of changes over time; only four communities have harvest data separated by more than 10 years. Where time series data are available, the results typically indicate changes but no clear directional pattern (Fall et al., 2013) in either total harvest or the relative proportions of different species. We further note that the available data are predominantly from the 1980s, which may not reflect current ecological conditions. Our analyses and our ability to interpret our results are thus limited by the data that are available.

Table 1
Communities and years for which we used harvest data. Note that only four communities have harvest surveys separated by more than a decade and the predominance of studies are from the 1980s.

Community	Years with harvest data
Akutan	2008
Alakanuk	1980
Atka	1994
Barrow	1987, 1988, 1989
Brevig Mission	1989
Clark's Point	1989
Dillingham	1984
Egegik	1984
Emmonak	1980, 2008
False Pass	1998
Golovin	1989
Igiugig	1983, 1992
Kaktovik	1985, 1986, 1992
Kivalina	1964, 1965, 1982, 1983, 1992, 2007
Kotlik	1980
Kotzebue	1986, 1991
Manokotak	1985, 1999
Nelson Lagoon	1987
Nuiqsut	1985, 1993
Nunam Iqua	1980
Pilot Point	1987
Point Lay	1987
Port Heiden	1987
Quinhagak	1982
Savoonga	2009
Saint George	1994
Saint Paul	1994
Shishmaref	1989, 1995
Togiak	1999, 2008
Tununak	1986
Twin Hills	1999
Ugashik	1987
Unalaska	1994
Wainwright	1988, 1989
Wales	1993

To visualize harvest patterns among Alaskan coastal villages, we used non-metric multidimensional scaling (NMDS), with Manhattan distance (Minchin, 1987, Legendre and Legendre, 1998). This is an ordination technique similar to principal component analysis (PCA), reducing the high-dimensional space of distances between many villages and many prey taxa, to (in this case) two dimensions. These new axes are set up to capture a high proportion of the information within the entire dataset. In contrast to PCA, NMDS does not rely on linear relationships, and allows for an easy visual inspection of which harvested taxa were most associated with which group of villages.

To formally examine the natural groupings of subsistence harvests of Alaskan coastal villages, we applied two different algorithms (see Legendre and Legendre, 1998): hierarchical cluster analysis and k-means. For both cases we first standardized the data by expressing the harvest data as proportions of the total harvest per village, then calculated a Manhattan distance matrix based on the harvest data. For hierarchical clustering we used the Ward algorithm. Hierarchical clustering matches the closest neighbors from the leaves to the root. K-means on the other hand work without this hierarchy, looking for the k groups that minimize among group variance. To facilitate comparison with hierarchical clustering, we used the same number of groups (3) for the k-means analysis as we extracted from the hierarchical cluster analysis. To allow better comparisons of our results with those of Sigler et al. (2011), we also ran the cluster analysis after aggregating the data over six eco-regions, five as defined by Sigler et al. (2011), plus the Aleutian Islands (Fig. 1).

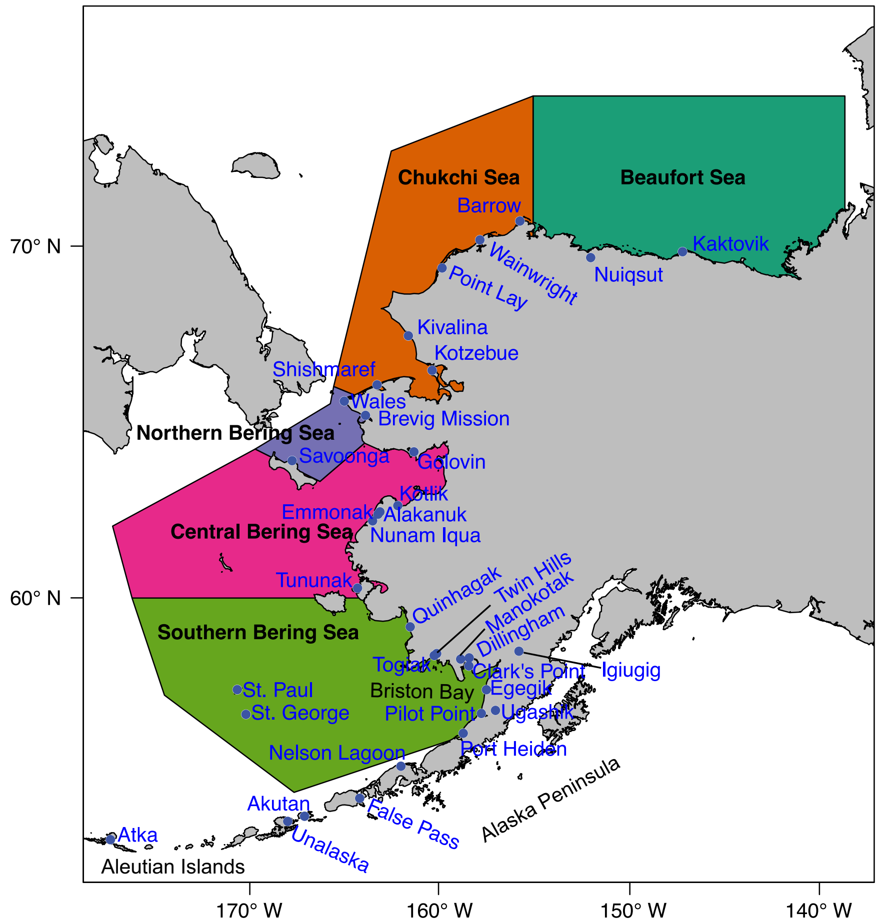

Fig. 1. Study area, location of villages and ecoregions described in Sigler et al. (2011) and also used here. We grouped the remaining villages along the Alaska Peninsula and in the Aleutian Islands as “Aleutian Archipelago”.

3. Results

The first major axes of our non-metric multidimensional scaling reveal a tight cluster of villages on the low end of the NMDS1-axis (Fig. 2, left) and a loose cloud at high values (Fig. 2, right). The cluster on the left corresponds to villages in the Bristol Bay and Yukon-Kuskokwim-Delta region, which tend to harvest ducks and nearshore fish, including smelt, pike, and salmon. These villages are also in close geographic proximity (Fig. 1). On the opposite end of the primary axis (NMDS1) are villages on islands in the central and northern Bering Sea (St. George to Savoonga), which tend to harvest seabirds (like auklets, cormorants, and kittiwakes), pinnipeds and halibut. The second major axis (NMDS2) features villages in the far north on the Beaufort and Chukchi Sea coast (Point Lay to Kaktovik), associated with whale, polar bear, eider, and arctic fish (grayling, cisco, and whitefish). On the lower extreme are southern villages like Unalaska, and Tununak, associated with fish and other seafood (scallops, mussels, capelin, eel, wolfish, octopus,) and puffin.

The cluster analysis by village reveals three large groupings, separated by comparatively long branches (Fig. 3). Mapping these three clusters reveals strong geographic patterns (Fig. 4A). The first major division (Fig. 3) divides inshore coastal mainland villages from the Kotzebue Sound to Atka Island (left box). The remaining villages can be further grouped into arctic villages, from villages from Point Lay north on the Chukchi and Beaufort Seas on the one hand (middle box), and more oceanic and southern villages on islands of the Bering Sea and on the southern Chukchi Sea (right box, Figs. 3 and 4A).

Using k-means as an alternative approach, we find similar results (Fig. 4B). The northern and oceanic villages still form one group. The remaining villages were split into a group of villages on the Alaska Peninsula/southern Bristol Bay, and the remaining villages on the eastern coast of the Bering Sea. The one geographic outlier was Nuiqsut on the Beaufort Sea, oddly grouped with the villages on the Alaska Peninsula.

Aggregating the villages by the eco-regions defined by Sigler et al. (2011) prior to analyzing the harvest structure and applying a hierarchical cluster analysis to the aggregates, we find two main clusters (Fig. 5): an arctic group (northern Bering, Chukchi and Beaufort Seas) and a subarctic group (central Bering, southern Bering Seas, and Alaska Peninsula/Aleutian Islands). Within these two main groups, geographically adjacent regions were clustered together.

4. Discussion

Our analysis of village-by-village and regional patterns in the composition of subsistence harvests shows a predominantly geographical signal, likely reflecting ecological patterns. Hierarchical cluster analysis and groupings by k-means both find a major division in harvest patterns between the coastal villages of western Alaska and villages in on the Beaufort and Chukchi Seas and Bering Sea Islands. We can therefore observe a North–South division on the shore of mainland Alaska with a break point near Point Hope. By contrast, within the Bering and southern Chukchi Seas we find an East–West division. Our village-level analysis did

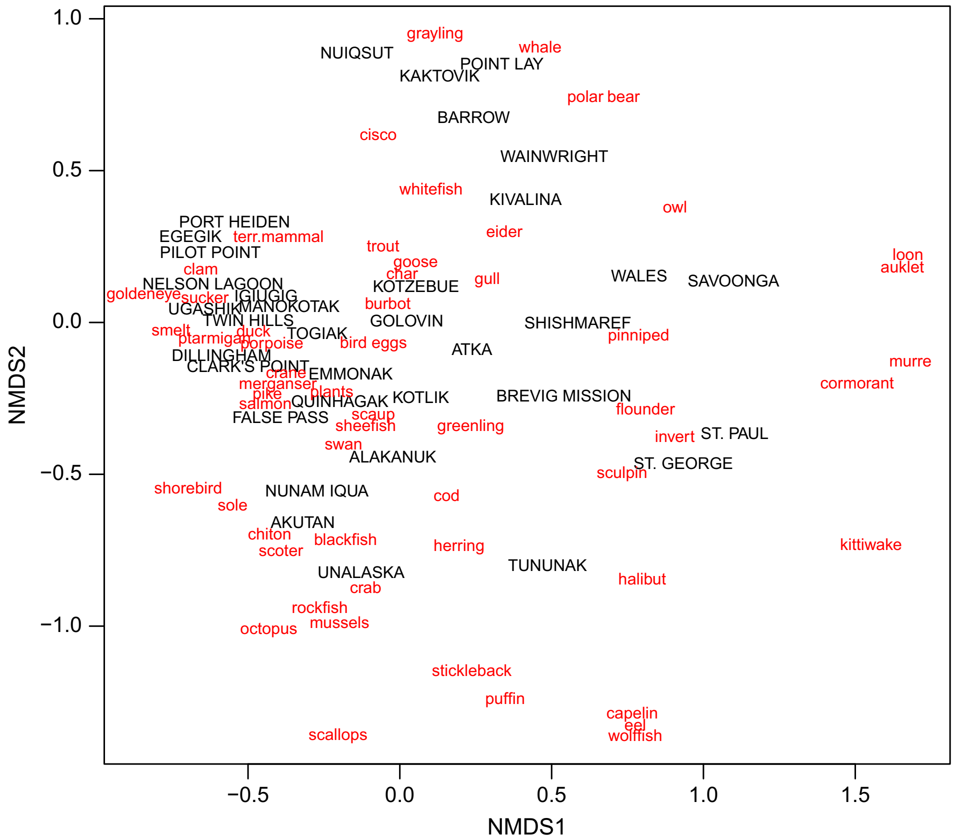

Fig. 2. The first two axes of a non-metric multidimensional scaling using Manhattan distances. Villages are shown in upper case black, harvested taxa in red. Harvested taxa close to a particular village does not indicate that those taxa are a dominant part of the harvest, but that they are relatively more commonly harvested there than elsewhere. The non-metric fit has a $R^2 = 0.985$, indicating that the analysis represents the multi-dimensional data well. Overlapping labels were moved slightly to make them legible. The full species names are given in the appendix. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

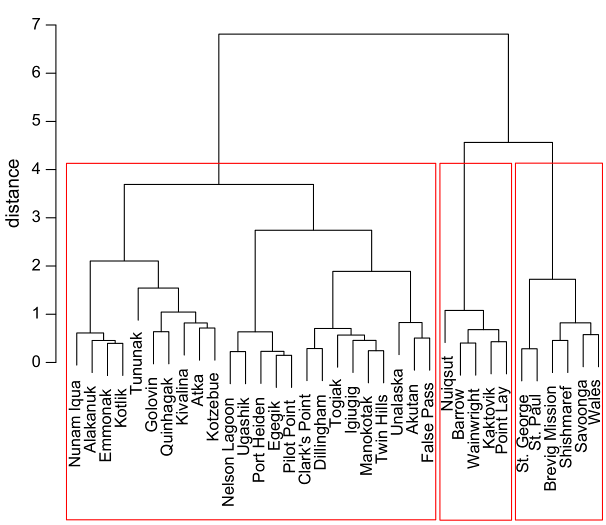

Fig. 3. Hierarchical clustering of communities by subsistence harvest characteristics. We used the Ward clustering algorithm on Manhattan distances. The boxes highlight the three most prominent, supported by long branch lengths, and also geographically coherent clusters.

not detect the North–South divisions within the Bering Sea, as proposed in Stabeno et al. (2012), although the regional analysis (Fig. 5) separates the northern Bering Sea from the central and southern Bering Sea.

The observed East–West division within the Bering Sea is a remarkably close match to ecoregions proposed by Piatt and Springer (2007). Both approaches found the major ecological division in the eastern Bering Sea to run East–West, instead of North–South. Both approaches also grouped the region around Kotzebue with inland waters farther south in the Bering Sea, rather than with those in the nearby Bering Strait, or places north along the Chukchi Sea. Our hierarchical cluster analysis detected a break point near Point Hope, also in agreement with the ecoregions proposed by Piatt and Springer (2007).

We also note that the patterns of subsistence harvests in northern Bering Sea are in general agreement with the East–West divisions one would predict based on physical and biological oceanography. Prevailing ocean currents in the Eastern Bering Sea run south to north (Coachman et al., 1975; Sigler et al., 2011). Several distinct, parallel currents flow through the area, each carrying characteristic water masses. The Alaska Coastal Current carries Alaska Coastal Water (ACW) over the shelf and through eastern Bering Strait (Coachman et al., 1975). ACW is poor in nutrients and large zooplankton (Kachel et al., 2002; Coyle et al., 2011). To the west of the ACW are the Bering Shelf Water and Anadyr Water (Sigler et al., 2011), both more saline and richer in nutrients and zooplankton than ACW. However, our data are not sufficient to resolve differences at such a fine scale.

Nuiqsut, on the Beaufort Sea coast, was the one disjunct outlier in the k-means analysis, being grouped with villages in Bristol Bay. Nuiqsut's harvest is characterized by a mix of marine mammals and fish rather than being dominated by marine mammals, as is the case for other North Slope villages. The inhabitants of Nuiqsut hunt bowhead whales, though they were not successful in every year surveyed (one out of two). Also, Nuiqsut is located in the delta of the Colville River, making it a favorable location for fishing.

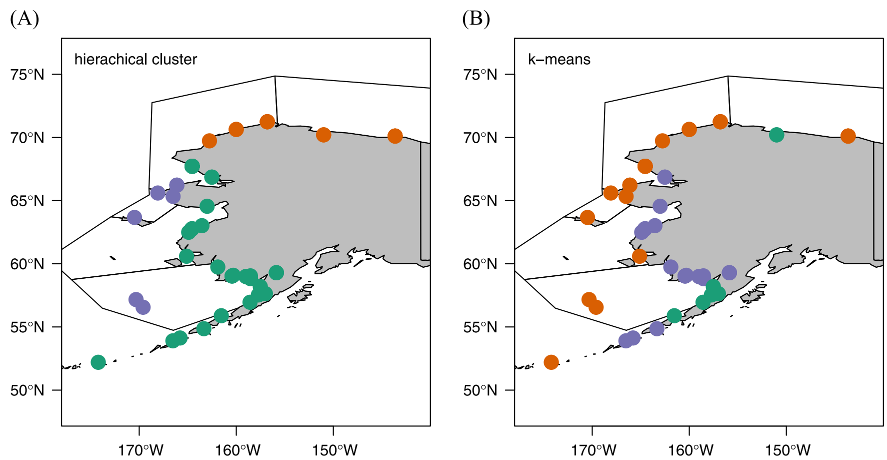

Fig. 4. Village locations indicating major cluster group by color for the two approaches used. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

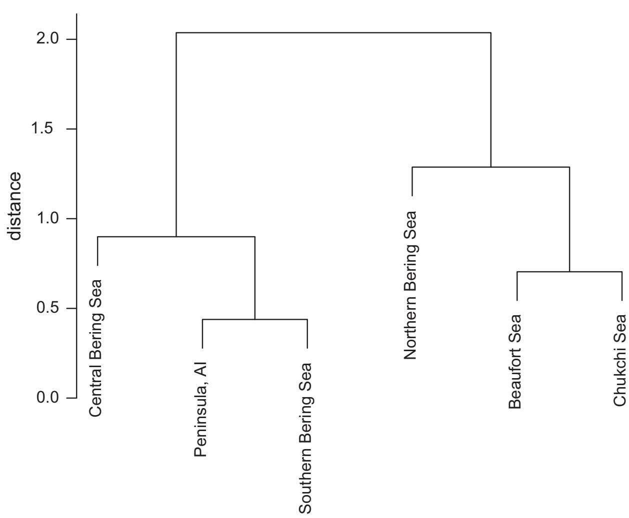

Fig. 5. Affinities of six oceanographic regions (from Sigler et al., 2011) according to subsistence harvest patterns. Details as in Fig. 3.

Thus, it may not be surprising that their harvest composition has greater balance between fish and marine mammals than do the communities in the northern cluster, which relied more exclusively on marine mammals. Within the hierarchical cluster analysis (Fig. 3), Nuiqsut is at the basal branch of the arctic cluster, indicating that it is somewhat distinct from the remaining villages, which is also supported by the NMDS analysis.

Many of the communities in the southeastern cluster, characterized by a predominance of fish, are concentrated around the greater Bristol Bay area, one of the richest salmon fishing areas in the world (Salomone et al., 2011). This group extends north to the Chukchi Sea coast and out the Aleutian Island chain, an affinity that is less obvious but likely reflects a common element of a substantial fish harvest. Communities on Bering Sea islands and the western Seward Peninsula make up the southwest cluster, characterized by a mix of fish and marine mammals. Salmon are not as abundant here as in the southeast region, but other fish such as Pacific halibut (*Hippoglossus stenolepsis*) and whitefish (*Coregonus* spp.) are caught in greater numbers. The non-metric multidimensional scaling analysis indicates that it was the harvest of seabirds, like murres and kittiwakes, as well as seals that set the harvest practices of these villages apart. The northern cluster is dominated by the production of marine mammals, including ice seals, walrus, bowhead whales, and beluga whales (*Delphinapterus leucas*).

The finer-scale clustering shown in Fig. 3 also shows a strong geographical signal. The Iñupiaq communities of Barrow and Wainwright are close in space, and close in the cluster diagram. St. Paul and St. George are the two Aleut communities on the remote Pribilof Islands, and are most closely affiliated with each other. Alakanuk, Kotlik, Emmonak, and Nunam Iqua are the four Yupik communities in the Yukon River delta, and they group tightly together. The Aleut communities of Unalaska, Akutan, and False Pass represent the Eastern Aleutian Islands and form one group in the cluster analysis. The villages of Brevig Mission, Savoonga, Shishmaref, and Wales are also tightly grouped. Brevig Mission, Shishmaref, and Wales are all Iñupiaq communities and have historical ties in addition to geographic proximity, so this grouping is not surprising. Savoonga is a St. Lawrence Island Yupik community, however, so its inclusion in this group appears to have little to do with culture or history.

By contrast, Kotzebue and Atka were paired with one another, despite great geographical separation (Arctic to Aleutian Islands, about 1750 km in a straight line) and being culturally distinct (Iñupiaq vs. Aleut). The NMDS plot (Fig. 2) shows both villages near the center of both major axes, indicating that the harvest patterns of both villages were close to the average. While this may indicate the clustering of these two villages to be spurious, both places share high harvest levels of terrestrial mammals, plants, marine mammals, and salmon.

We also examined results of the cluster analysis in terms of the cultural affiliation of the villages (Krauss, 1982). No pattern was apparent. The northern cluster (middle box in Fig. 3, orange dots in Fig. 4A) is homogenous, including only North Slope Iñupiaq communities. But not all Iñupiaq communities join this cluster. The southeast cluster (left box in Fig. 3, green dots in Fig. 4A) is largely Yup'ik (15 communities), with five Aleut communities along the Alaska Peninsula and at the base of the Aleutian Island chain, and three Iñupiaq communities, including two on the Chukchi Sea coast. The southwest cluster (right box in Fig. 3, purple dots in Fig. 4A) includes three Iñupiaq, one St. Lawrence Island Yupik, and two Aleut communities. While cultural patterns may contribute to some more subtle characteristics of the groupings (e.g., the proximity geographically and in the cluster analysis of the two Pribilof Island communities, and the similar proximity of Brevig Mission, Shishmaref, and Wales), any differences in subsistence practices and cultural food preferences appear to be modest in comparison with biogeography in determining the groupings by subsistence harvest (e.g., the inclusion of Savoonga in the same small cluster as Brevig Mission, Shishmaref, and Wales).

The analysis of aggregated harvest data for six eco-regions (Fig. 5) allows a comparison with a similar analysis conducted by Sigler et al. (2011) on the clustering of biological communities of small zooplankton, large zooplankton, bottom fish, surface fish, and seabirds. Given that harvests include fish and seabirds but not small zooplankton and that only a few taxa that could be included in 'large zooplankton,' we may expect greater agreement between the results for harvest data and those for fish and seabird communities (Renner et al., 2012). In agreement with the cluster analyses of seabird, bottom fish, and large and small zooplankton communities, the harvest data clustered the southern and central Bering Seas together. The Chukchi and Beaufort Seas clustered together for the harvest data and also for bottom fish, but not for seabirds.

The topology of the cluster dendrogram in Fig. 5 differs from those presented in Sigler et al. (2011), where in four out of five cases, the northern Bering Sea clustered most closely with the Chukchi Sea, in contrast to the Beaufort-Chukchi cluster in the harvest data. This is not surprising in that Chukchi Sea water originates in the northern Bering Sea, passing through Bering Strait as several distinct water bodies (Hunt et al., 2013), blurring the biological distinction between the southern Chukchi and the northern Bering Sea. The greater affinity of the Chukchi Sea with the Beaufort Sea in the harvest clusters is consistent with the grouping of the northern cluster of communities in the village-level analyses. This may reflect the harvest of wide-ranging marine mammals, or be a cultural signal, or result from the fact that there are only two communities on the Beaufort Sea coast, making a limited sample for analysis. Note that Nuiqsut, one of the two Beaufort villages, joins a very different group in the k-means analysis, suggesting that its harvest pattern is not wholly consistent with that of other North Slope communities (all of which group together in both analyses).

While it may be tempting to invoke cultural factors for these differences, our analysis based on individual villages reveals more details: the main division in the southern Chukchi and northern Bering Seas does not run east–west but north–south, separating inshore waters (where fish and birds are primary targets of the harvest) and offshore waters, where marine mammal harvest is dominant. The regions used in Sigler et al. (2011) did not match the divisions that emerge from our village-based cluster analysis. This mismatch and the more pelagic sampling of the taxa used in Sigler et al. (2011) may be the primary causes of the mismatch in topologies.

In summary, our results indicate that people harvest what is available, and what is available depends on the biogeographical characteristics of their area. Thus, subsistence harvest data can broadly be regarded as ecological sampling data. The precise affinities among communities and regions are sensitive to the type of analysis being done and the characteristics in question. It is possible that greater differentiation of harvests at the species level, instead of aggregations of species groups due to lack of detailed harvest data, might reveal additional patterns that reflect the distributions of species within genera or other taxonomic classes. For example, a similar analysis could be done with more detailed data on subsistence harvests of waterfowl or salmon (much of which are available at ADF&G, N.D.a), though these datasets do not include the full range of subsistence species and thus correspond to sampling of a single taxon rather than an ecosystem. Nonetheless, the patterns are broadly consistent with other ecological analyses of the region, suggesting that subsistence harvests can serve as a useful proxy for ecological sampling. Future studies that document changing patterns in subsistence harvests, if supported by time series data for a sufficient number of villages, may also be able to shed light on ecological changes occurring in the Bering, Chukchi, and Beaufort Seas.

Acknowledgments

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.dsr2.2014.03.005.

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