Proposal

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# Background on nearshore fish research

## Topic introduction

The marine nearshore is the relatively narrow band of waters along any oceanic coast. It is an environment that provides important ecosystem services for numerous fish species. Most notably the nearshore strongly impacts juvenile life stages through habitat benefits as described in the nursery role hypothesis. This hypothesis and related concepts were made popular in the 1990’s and its study continues in the current literature. Recently researchers have incorporated findings from other fields of ecology and statistics, as well as adopting new approaches to data collection and analysis afforded by modern technologies.

Much of the contents of the nursery role hypothesis have become paradigm (e.g., reduced predation), supported by numerous studies documenting the occurrence, abundance, and growth of fish species in nearshore habitats. In the last decade or so, there has been strong support in the literature for expansion of nearshore benefits to include ideas like habitat connectivity and ‘seascape’ effects. These migration-dependent topics have mostly been studied for singular taxa due to fisheries management priorities and cost-prohibitive study designs. While community assessments are widely conducted, relatively little is known about community-level effects in terms of how nearshore nursery functions with other ecological mechanisms that are known to affect fishes, such as species interactions, trophic dynamics, or changes to habitat quality (e.g., shifts from OA or other physicochemical conditions).

Issues of scale add an additional level of complexity to our understanding of communities in relation their environment. As in other fields of ecology, scale-related effects are a necessary hurdle to overcome for research to generalize beyond the site or system level. In the last few decades, increased attention to climate effects have linked anomalous environmental observations to fisheries responses and raised management concerns for future resource availability and quality. In areas where long-term environmental data exist, nearshore fish metrics can be related to multi-year or decadal patterns, or to periodically defined events (e.g., historic floods, MHWs, oil spills). Climate measurements exhibit basin-wide patterns but will also vary among sites. Similar spatial scales in nearshore fish data must be addressed if parsing variance over time, or vise versa if parsing in space.

## Community structuring

Nearshore fish community structure has been researched globally for decades, where a particular density of studies come from temperate regions of Europe, Australia, and South Africa. Although relatively less prominent in the literature, large-scale informative studies also exist from tropical and more polar regions. Most bodies of research have started at the local scale comparing community structure (as alpha and beta diversity) to physicochemical conditions among sites that are 0-10 km apart. The studied conditions are typically hypothesized a priori and have resulted in significant effects from temperature, salinity, turbidity, or water velocity. Numerous other metrics of water quality and physical conditions have also been found to be important. However, which parameters that result in highest impact can differ based on the study area, and so early studies tend to acknowledge uncertainty when translating their findings to other systems. Comparison of habitat types is another common study design at the local scale. A review of such work found that structured habitats (e.g., seagrass, mangroves, kelp forests) are almost always more beneficial in terms of nursery role functions than unstructured habitats (e.g., bare substrate, low rugosity).

At larger spatial scales, variability in community structure is dominated by factors that differ among ecosystems, such as latitude and coastal formation, rather than those that more so characterize the site level like hydrology or habitat. Latitude, or more generally distance, affects the overall regional pool of species on the scale of 1000s of km. Additionally, communities are either described in the context of marine or estuarine settings (sometimes referred to as ‘transitional waters’) because of the physiological limits which produce euryhaline-adapted fishes. Studies also find differences in community structure when comparing systems with contrasting geomorphologies. These comparisons are somewhat intuitive at a system-wide scale (100s of km), where researchers can easily delineate samples based on coastal types (e.g., open beaches, bights, fjords, lagoons) or associated features (e.g., watershed type, freshwater source, anthropogenic influence) using geographic calculations such as total area, shoreline complexity, or distance to features. Generally speaking nearshore communities vary at multiple spatial scales: differences among sites (beta diversity) can be attributed to a multitude of factors depending on the context of the study area; whereas, overall structure (gamma diversity) and its pattern across large scales (zeta diversity) are linked to similar spatial factors as those controlling the regional species pool.

Despite wide spatial variability, dominance by juvenile life stages in the community is ubiquitous among nearshore studies. So a popular topic in the recent literature has been assessments of structural change over time (another form of zeta diversity). Temporal variability in nearshore fish communities has been widely reported at the seasonal level, and to a lesser degree across multiple years. Seasonal patterns of occurrence and abundance are largely influenced by the different life history strategies that occur among taxonomies, such as the various forms of diadromy. Residence and timing of fishes have also been related to prey availability, hydrological disturbances, and proximity to other habitats, among other (often system-specific) factors. Studies that include interannual variability have typically reported on shorter periods (~2-4 yrs), which is insufficient data to discern whether observations represent a community response to environmental change or if caused by population dynamics which are known to fluctuate across years in many fisheries.

A handful of areas have now accrued longer time series of community observations, and usually they have coupled these data with nearby long-term environmental monitoring datasets or oceanographic oscillation indices (e.g., ENSO, NAO, PDO). When these analyses have been conducted, researchers have found structural changes linked to anomalous temperature patterns, basin-level regime shifts, and downstream climate effects (e.g., hydrological regime shifts). While consistent yearly datasets are hard to come by, comparisons among periods separated by multiple years (i.e., before, during, or after events) are more common in the literature. Studies have found significant changes in community structure coinciding with these periodic comparisons, where large disturbances (e.g., MHWs, habitat alteration) have correlated with disruptions in seasonal residency, abundance, and growth. There is evidence that nursery functions may be reduced due to MHW disturbances, although marine protected areas may have a mitigating effect during and after these periods. The overall community response to long-term changes is a useful criteria for discovering structural shifts attributed to climate as opposed to interannual variability. However, identifying the exact mechanisms that drive those community changes likely still lies in our understanding at the individual species and population level.

## Findings from Alaska

As with most of our understanding of fishes in Alaska, early research on nearshore communities stems from resource management interests. Community-level studies began in earnest in the 1970’s when state and federal agencies sought biological assessments for emergent fisheries and lease openings for oil extraction. These early coastal studies were focused around the Beaufort Sea, SEAK, and northern GOA, and in the latter specifically Kodiak, lower Cook Inlet, and Prince William Sound. Additional community assessments have since been conducted (ca. 1990s to now) expanding the existing sample area coverage but also creating new datasets from parts of the Aleutian Islands, Bering Sea, and Chukchi Sea. However, nearshore fish information still does not exist for most of Alaska’s huge coastline. Compared to other nearshore fish research across the globe, Alaska has sparse data relative to its size. These gaps can be filled to some extent by fisheries-specific studies which have been much more frequent and widespread throughout the state. Additionally, spatial models have become more feasible in the last couple of decades, associating fish with coastal datasets like habitat maps or hydrological observations. Although, relatively few of these studies have been conducted.

Alaskan nearshore fish communities include the juveniles of target fisheries and forage species. Due to their cultural and economic importance, much of our understanding of nearshore habitat usage comes from research targeted at salmonids and groundfish, including five Pacific salmon species, walleye pollock, Pacific cod, and various flatfishes. Juvenile salmon migrate into the nearshore in spring and early summer on their way to offshore adult habitats. This short-term nearshore residence is hypothesized as critical in terms of growth and energetics related to adult marine survival; however, limited means to track populations in the open ocean makes the exact impact of the nearshore difficult to discern from other ecosystem influences. Pollock and cod hatch in offshore waters in late winter then currents transport larva into the nearshore to rear throughout the warm summer months. Once settled in the nearshore, gadids exhibit a habitat preference for seagrass and subcanopy kelp beds but also migrate among less-structured habitats in close proximity. Flatfish species, such as Pacific halibut and rock sole, also hatch offshore then rear in nearshore waters during summer. But by contrast, flatfishes tend towards unstructured habitats associated with mostly sand or fine-grain substrates. Except for salmon which are known to rear in rivers for multiple years, these young-of-the-year fishes will migrate to slightly deeper marine depths during winter and return to shallow habitat the next summer. But similarly as salmon, some species will do this two or more times before moving on to adult habitats. Some of the most important forage species in Alaska also exhibit this annual shallow-to-deep (summer-to-winter) migration. Although, forage species differ somewhat because they also use nearshore habitat as spawning grounds (e.g., herring), including in the intertidal (e.g., sand lance) or in adjacent low-river stretches (e.g., eulachon). Actually, the large majority of nearshore community members exhibit some seasonal patterns in migration and/or growth. This is why community analysis almost always attribute a large portion of overall variance to seasonality.

The study areas where assessments occurred in the 70’s are still the most consistently sampled areas today. The nearshore nursery role is consistent within each area’s body of work, but the research focus often differs in terms of target species or habitat factors deemed influential. Nearshore research from the Beaufort Sea and Chukchi Sea stand out more so than others because of the difference in species pool at Arctic latitudes, with many studies focusing on Arctic cod in particular. Although, recent evidence of species borealization (e.g., increase in saffron cod abundance) suggests an ongoing shift in the community. Arctic research has also uniquely investigated the community structure of lagoon habitats, as well as identifying wind as a significant factor in structuring beach communities. Southeast AK has perhaps the largest body of work, with numerous coastal towns (relative to the rest of Alaska) and multiple marine research institutions based in the area (UA, ADFG, NOAA). Compared to other regions, SEAK nearshore research includes a more diverse array of topics including differential habitat usage among juvenile rockfishes, importance of seagrass beds for juvenile salmon, hatchery salmon impacts, hydrological influences from watershed features (e.g., glacial coverage or snowpack), and trophic dynamics of estuarine residents (e.g., staghorn sculpin, dolly varden, starry flounder). Prince William Sound has also developed a relatively dense body of work, and similar to SEAK has examined nearshore roles concerning juvenile rockfishes (i.e., copper and lingcod), hatchery salmon, and habitat comparisons between seagrass and kelp beds among others. Unique to PWS is a large knowledge base concerning the area’s Pacific herring, which stems from a strong interest in understanding its population crash after the Exxon Valdez oil spill in 1989. Similarly, research in Lower Cook Inlet can attribute some of its efforts to oil spill recovery as historic and recent oil leases prompted environmental assessments in the area. LCI research has produced studies on habitat preferences in juvenile flatfish (e.g., arrowtooth, halibut, rock sole) and oceanographic structuring of forage fish populations (e.g., capelin, gadids, Pacific sand lance). An interesting aspect of this forage fish research has been a focus on energetics, feeding, and spawning behavior of local Pacific sand lance populations. In Kodiak, an impressive body of work has been built describing the recruitment, habitat preference, and growth of juvenile pollock and Pacific cod over multiple years. One important finding has been the reduced effect of nursery habitat on gadid success during marine heatwave periods, suggesting that the timing of hatch date was most influential in determining the success of YOY cohorts.

While the study areas highlighted above have maintained different research themes, there has also been a fair amount of cross pollination among the various parts of the state (e.g., a Pacific halibut study from the Bering Sea), as well as contributions that span multiple areas and taxa. Most of our understanding of regional comparisons in nearshore communities comes from studies of the latter type, although these usually concern singular species or a group of species (e.g., a forage fish study across the northern GOA). Juvenile salmon and gadid research has been the most widespread in Alaska since these taxa are relatively commonplace and receive increased attention for resource management reasons. An example outcome of this was a recently produced species habitat model linking pollock and cod juveniles with physical coastal features in both SEAK and PWS. Other widespread topics include the study of similar environmental drivers of species or community metrics. These often include the physicochemical parameters of temperature and salinity, and habitat factors like structure type and density (as in seagrass beds) or other physical descriptors like depth and substrate. Direct regional comparisons at the community level have been few and far between. However, some studies have examined variability in community among multiple systems (e.g., comparison of sites within and among embayments), for example across larger areas (1000s of km) like the northern GOA, PWS, SEAK, and the Arctic. Seasonality and habitat factors (e.g., kelp vs seagrass) were commonly reported influences on diversity and abundance, as well as structural differences in community linked to landscape-derived factors and interannual comparisons. A recent study comparing two systems, Kachemak Bay in LCI and Lynn Canal in SEAK, reported a regional difference in community mean and variance driven by contrasting hydrological settings. The more ocean-exposed Kachemak Bay exhibited interannual variability in taxonomic structure correlated with temperature, salinity, and turbidity; whereas, community variability in the more freshwater-exposed Lynn Canal had a weak interannual effect and instead exhibited stronger seasonal effects relating to salinity and watershed discharge. This same study looked at functional diversity, which had not previously been done on nearshore fish communities in Alaska, and found weak correlations with local conditions in both systems. This suggests that if temporal shifts occur (over years) in nearshore fish communities then drivers are likely operating at larger spatial scales instead of smaller ones.

# Dissertation theme

Community analysis was developed recognizing ecological principles based on species interactions and was meant to address questions of biodiversity, conservation, management, and change over time, where single-taxa studies were either inadequate (e.g., too costly or time consuming to string together) or simply inappropriate (e.g., need for samples coupling multiple taxa). While nearshore fish research in Alaska has been built over multiple decades, the information available in the literature lacks cohesion in terms of data analyses, ecological interpretation, and future outlook at the community level. In the last decade, other branches of ecology have led the way in performing analyses from a community perspective (e.g., multivariate inference models, joint species distributions, variable reduction). Some of these methods have already been applied to Alaskan nearshore fish communities, namely ordination and ANOVA based approaches. However, broad-scale analyses are still a gap considering the breadth of available datasets in both time and space compared to what has been done in other parts of the world. My dissertation aims to develop a cohesive understanding of nearshore fish community variability at the local-to-system scale, as well as at the region-to-region scale, and to examine if and how communities have changed over longer time periods. In my opinion, these are requisite analyses that will result in useful outcomes for fisheries management and ecosystem models, and will lead to next step analyses like those found in other branches of ecology.

# Proposed chapters

For chapter 1, I ask which physicochemical parameters and habitat factors structure nearshore fish communities within a system. Namely, I examine variance partitioned among temperature, salinity, tubidity, bay location, and site exposure (protected vs exposed) as water velocity. The goal of this chapter is to build upon existing knowledge of a well-studied system, and further our understanding of system-wide influences on community structuring.

For chapter 2, I ask how nearshore fish communities are structured at varying spatial scales. In this chapter I expand the scale of study to include samples spread across multiple systems, first examining spatial autocorrelation and then parsing community variance among grouped samples (system-to-regional scales) with coastal habitat features that vary at the local level. The goal of this chapter is to uilize the range of data available in Alaska (namely the Gulf of Alaska) to empirically determine appropriate spatial groupings of community samples for further analyses.

For chapter 3, I ask if and how nearshore fish communities have changed over long-term periods (years-to-decades) coinciding with known climate-related trends. Specifically, I look for patterns in community variability surrounding the marine heatwave that affected the Gulf of Alaska from 2014-2016. The goal of this chapter is to apply findings from other nearshore fish research which hypothesized effects on nursery function during years with anomalously warm water temperatures.

# Approach

An early review of initial nearshore fish community assessments described a variety of gear types utilized, including trawls, seines, passive nets (e.g., gill, try, fyke), hook-and-line, and SCUBA. Each gear type resulted in different community assemblages, but beach seines had the lowest selectivity especially in inshore areas where juveniles are most accomodated according to the reduced predator paradigm. In chapter 1, I collect new data in the study area of Kachemak Bay which represents a relatively well-studied system in terms of historical community assessments and published findings. This will provide me with a firm grasp of the sampling method, which will allow for a better understanding of how samples should be treated in data preparation and analyses. In chapters 2 and 3, I leverage the NOAA Nearshore Fish Atlas of Alaska database which aggregates data from numerous studies (~20) conducted over multiple years (ca. 1990s to present). I will subset the NFAA and perform data preparations to fit the research question in either chapter. Although, I expect to focus on data collected from the GOA broadly (from SEAK to Aleutian Islands) due to the density of studies on hand, as well as existing broad-scale ecosystem definitions (e.g., east vs west GOA) that can be tested using nearshore fish data which would be novel.