**Introduction**

Anthropogenic climate change will impact nutrient cycles, primary productivity, and thus ecosystem structure in the world’s oceans, although considerable uncertainty still exists regarding the variability of these changes and how ecosystems will respond. Changes in primary production has implications for dependent marine ecosystems, as it influences abundance and interactions in both adjacent and non-adjacent trophic levels (Ware and Thomson 2005, Winder 2012, Frank et al. 2015). This bottom-up control of marine food webs is expected to reduce fishery yields by as much as 20% globally by 2100 due to productivity constraints at lower trophic levels (Moore et al. 2018). Given both resource availability and community composition of resources impact the function and stability of food webs (Narwani and Mazumder 2012) it is likely ecosystem interactions will change in response to environmentally induced shifts in resources in the future.

Ecological interactions are a fundamental component to studying the function and dynamics of ecosystems. Currently, anthropogenic and climatic changes are altering ecological interactions at a global scale, thus, understanding how interactions function and how environmental perturbations will alter interactions is imperative. Studies of environmental control of food webs are often limited to only examining low trophic level species (Pershing et al. 2010), or only include indices of either primary production or environmental change (Ware and Thomson 2005, Chassot et al. 2007). Oceanic conditions such as sea surface temperature, freshwater discharge, wind, and ice cover, have been linked to abundance and recruitment of many fish species in the Northeast Pacific (Cunningham et al. 2018, Puerta et al. 2019, Stachura et al. 2014), but studies rarely include proxies or indicators of either nutrient availability or primary productivity that enable mechanistic understanding of ecosystem response to the environment.

Lower trophic levels are sensitive to environmental variation in bottom-up drivers of productivity (sensu. Ware and Thompson 2005, Frank et al. 2006, Jennings and Brander 2010), but few studies have demonstrated how the impact of these changes span entire food webs on long time scales. Additionally, somatic growth of large bodied marine predators is not continuous and typically occurs on a longer temporal scale than phytoplankton dynamics making it challenging to link higher trophic level species to forcing lower in the food web. Similarly, marine predators can utilize resources at multiple spatiotemporal scales, creating a challenge for linking species abundance to independent observations of phytoplankton or nutrient dynamics. How environmentally induced changes in primary productivity ultimately influences nutrients available to and assimilated by the food web is thus poorly understood.

An empirical understanding of food web responses to environmental drivers requires long time series data that span multiple changes in climate regimes to decouple natural oscillations with long-term changes (Litzow and Cianelli 2007, Cury et al. 2008, Tallis et al. 2010, Hastings et al. 2018). In recent decades extreme changes in marine environments have become more common and these events have had substantial impacts on ecosystems. Marine ecosystems in Alaska are experiencing unprecedented environmental change that has altered abundance and size distributions of many fish species (Barbeaux et al. 2020, Holsman et al. 2019, Oke et al. 2020, Suryan et al. 2021). More recently, atmospheric circulation anomalies in the northeast Pacific Ocean have resulted in abnormally warm sea surface temperatures during the past decade (Walsh et al. 2018) and this environmental shift has altered fish abundances (Bond 2015, Litzow et al. 2020). For example, the unprecedented marine heatwave that occurred in 2014 - 2016 triggered dramatic ecosystem change, including a 71% decline in Pacific cod in the Gulf of Alaska (Barbeaux et al. 2020) and declines in phytoplankton biomass, forage fish abundance, and changes in community structure (Suryan et al. 2021).

Reconstructing time series of indicators of ecosystem interactions is important to understand how ecosystems have responded to environmental variability in the past and ultimately interpret potential food web responses to environmental conditions in the future; such datasets are distinctly lacking. Modern chemical analyses, such as compound-specific stable isotope analysis (CSIA) of inorganic nitrogen sources or amino acids, have potential to improve our understanding of food web interactions by 1) extending time series through retrospective analyses 2) identifying environmental forcing of the entire food web when measured in predators and 3) informing biologically relevant mechanisms of interactions, a former limitation of many ecosystem studies.

Analyses of nitrogen stable isotopes usually applies bulk stable isotope techniques which measures the 15N/14N ratio of nitrogen as a weighted average of all nitrogen present in a given sample. For tissue samples, 15N/14N measurements are a weighted average of the concentrations of all amino acids present in the protein of an individual tissue. For soil analyses, typically 15N/14N includes both organic and inorganic form. However, the 15N/14N of an individual compound, known as compound-specific stable isotope analysis, represents the kinetic and diffusive fractionation factors exerted on that compound through chemical conversions, typically from biogeochemical or physiological processes. Thus, nitrogen isotope values can provide a useful link between biogeochemical reactions that regulate nutrient availability and primary production, and ecological responses, without being confounded by nitrogen containing compounds that are not utilized by an ecosystem.

Here we aim to reconstruct historical food web interactions using stable isotopes as chemical tracers to:

1. Identify how long-term (20-years) changes in salmon abundance impact nitrogen dynamics in riparian soils.
2. Understand the how ocean conditions alter food web-assimilated nitrogen resources and primary production in the northeast Pacific
3. Identify dominant historical drivers of predator foraging ecology in the northeast Pacific, using trophic position as an indicator of major changes in foraging.
4. Establish a framework to improve trophic position estimation of bulk and compound-specific stable isotope analysis for historical and contemporary studies.

Abstract

Physical environments are changing globally due to anthropogenic impacts which has the potential to alter ecological interactions. To understand how ecological interactions are changing, long-term datasets are necessary to document ecological baselines from the past that are comparable to current ecological conditions. Stable isotope values can be useful chemical tracers for retrospective analyses which can elucidate changes in biogeochemistry and trophic interactions that influence food webs. My dissertation applies compound-specific stable isotope analysis (CSIA) of amino acids and inorganic nitrogen to understand long-term, regional, ecological responses to physical conditions in the northeast Pacific. I tested the long-term importance of salmon subsidies to Alaskan riparian ecosystems by measuring inorganic nitrogen concentrations, transformation rates, and nitrogen stable isotope values in soil following a 20-year carcass manipulation experiment. Carcass subsidies did not increase soil nitrogen concentrations or transformation rates but the nitrogen stable isotope value of ammonium was significantly enriched in 15N compared to salmon carcasses, indicating the importance of salmon derived nutrients is likely overestimated for some systems. Using museum skull specimens from two species of pinnipeds in the northeast Pacific, harbor seals (*Phoca* vitulina) and Steller sea lions (*Eumetopias jubatus*), I derived a century of predator stable isotope data. I compared the carbon and nitrogen stable isotope values of source amino acids to regional climate datasets and determined coastal food webs responded to climate regimes, coastal upwelling, and freshwater discharge, yet the strength of responses to individual drivers varied across the northeast Pacific. These findings demonstrate stable isotope data can serve as a tracer of nitrogen resources and phytoplankton dynamics that is specific to resources that are assimilated by food webs. To calculate pinniped trophic position from the historic dataset, I was the first to apply taxa-specific trophic enrichment factors, a system specific β-value, a temporal lag to account for tissue turnover time, and a multi-trophic amino acid analysis framework within a single study. This approach constrained assumptions regarding physiological processes and vascular plant contributions to the food web, which can confound stable isotope data interpretation. I analyzed long-term predictors of harbor seal trophic position in Washington and identified delayed responses of harbor seals to both physical ocean conditions (upwelling, sea surface, discharge) and prey availability (Pacific hake, Pacific herring and Chinook salmon). Consideration for dynamic responses of harbor seals to their environment is an important factor for understanding predator-prey interactions as harbor seals respond to multiple ecological factors that are often changing simultaneously and their response occurs at multiple temporal scales. I then analyzed regional and decadal trends in pinniped trophic position in Alaska and identified the largest change in trophic position occurred in recent decades (2000 and 2010) but the direction of the trends diverged based on region and species. Gulf of Alaska pinnipeds are experiencing unique food web conditions in recent decades compared to the past likely in response to climate-induced ecological change in the region. Finally, I constructed a compartment model to explore the effect of stable isotope heterogeneity and consumer isotope incorporation rates on consumer trophic position estimates using both bulk stable isotope analysis and CSIA. Bulk stable isotope analysis produced consistent errors in trophic position estimates by as much as one trophic level that were more pronounced in higher trophic level consumers and CSIA was more accurate than bulk stable isotope analysis. Altogether, these results show CSIA is a useful tracer for elucidating long-term physical forcing mechanisms on food webs and incorporating physiological processes that govern stable isotope fractionation into sampling and analysis design can uncover forcing mechanisms that would otherwise be overlooked.

- The enviornment is changing

-In order to understand how the environment is changing, we need data from the past

-Historical data for species abundance is usually avaialble and how the environment is changing species abundance is well documented across ecosystems globally

-Abundance is not the only important ecosystem component, we know species interactions are just as important for shaping and influencing ecosystems

-But historical indices of ecosystem interactions are rare and can be challenging to reproduce for modern datasets.

-Chemical tracers can be a useful tool for measuring ecological interactions especially on long timescales.

Here we use CSSIA of amino acids and inorganic nitrogen to assess changes in species interactions in teperate marine and riparian ecosystems.