ABSTRACT

Coastal upwelling regions account for 20% of global ocean productivity. These extremely productive wind-driven ecosystems are vulnerable to climate change. Here, I investigate relationships between the physical environment, primary productivity, and fisheries productivity in an Australian upwelling ecosystem. This study examines the likely impacts of climate change on the ecosystem productivity of a historically low-wind upwelling system. These results provide insight into the vulnerability of the ecosystem to climate change to help inform an ecosystem approach to marine management.

The large-scale investigation in Chapter 2.1 reveals bottom-up trophic control across a diverse suite of Australian marine bioregions, indicating that changes in primary productivity will cascade throughout foodwebs. Though primary productivity is clearly important, other oceanographic conditions are necessary for the viability of fisheries. Chapter 2.2 presents a comparative analysis of key oceanographic characteristics of several productive Australian ecosystems to assess how enrichment, concentration, and retention mechanisms regulate fisheries recruitment.

These large-scale physics-to-biology relationships are then assessed at the regional scale for the most productive upwelling system in Australia: the Bonney Upwelling. The Bonney Upwelling in south eastern Australia has classic enrichment, concentration, and retention features. This wind-driven system is vulnerable to climate change because of potential future changes in large-scale wind forcing. The productivity of wind-driven upwelling systems depends on an “optimal environmental window” in which wind speed is strong enough to promote vertical mixing of nutrients that enhance productivity, but is not so strong as to lead to deleterious turbulent mixing or pronounced advection that may
reduce productivity or lose spawning products to oligotrophic offshore waters. In Chapter 3, I show that the Bonney Upwelling region currently operates at low wind velocities (~4 m s\(^{-1}\)), and hence suboptimal productivity as wind velocities are less than the optimal environmental window (5-6 m s\(^{-1}\)). Statistical models are developed that describe between 40%-50% of the variation in phytoplankton biomass, using alongshore wind stress and the size of the upwelling plume as predictors.

In Chapter 4, I develop biophysical statistical models that describe relationships between regional and large-scale environmental drivers, primary productivity and catches of two commercial marine species. These species have contrasting \(r\)- (arrow squid, \textit{Nototodarus gouldi}) and \(K\)-selected (gummy shark, \textit{Mustelus antarcticus}) life history traits. I develop significant physics to biology relationships that describe ~77% of variance for arrow squid catch rates and ~50% of variance for gummy shark catch rates. Arrow squid are closely related to upwelling forcing and the regional environment on a seasonal time scale, and gummy shark have closer links to large-scale climate drivers (El Niño–Southern Oscillation) at periods of up to 3 years. The arrow squid biophysical model is useful for present-day and future predictions; however, due to complicated (non-linear) interactions in the gummy shark biophysical model, predictions for gummy shark populations are not useful.

In Chapter 5, climate models are used to make projections of potential impacts of climate change on ecosystem productivity for two likely CO\(_2\) emission scenarios (Special Report on Emissions Scenarios A1B, and A2). I find that the Bonney Upwelling is projected to remain a low-wind system as the magnitude of the wind is not predicted to substantially increase. However, alongshore wind stress events are predicted to intensify and become more prevalent, especially in the upwelling season. This is due to the southward migration of the subtropical ridge. The “business-as-usual” emissions scenario (A2) predicts an extension of the upwelling season by one month that affects intra-annual upwelling phases by shortening the onset of upwelling, extending the sustained phase of upwelling, and shortening or delaying the quiescent phase of upwelling. Primary productivity is expected to increase linearly with wind stress, with potential shifts in seasonal peaks. Arrow squid catch rates are predicted to increase due to stronger upwelling and warmer ocean temperature.

In this thesis, I apply ecological theory at both large and regional scales to Australian marine ecosystems. I develop robust, relatively simple methods to describe complex environment-biology interactions. This thesis demonstrates the value of simple statistical models to investigate complex ecosystem response to future climate change.