Chapter 1 VARIABILITY WITHIN PELAGIC ECOSYSTEMS OF PRINCE WILLIAM SOUND

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Introduction to Pelagic Ecosystem Monitoring

In the aftermath of the 1989 *Exxon Valdez* oil spill it was difficult to distinguish between the impacts of the spill and background variability in most populations. The main problem was that long-term baseline data for pelagic species were largely absent. As a result managers struggled to make informed decisions in their assessment of damages and recommendations for recovery. For example, marine birds had not been surveyed since the early 1970s and after the spill it appeared there had been major declines. Ten years after the spill it became widely recognized that there had been a major climatic regime shift that altered the entire marine ecosystem prior to the spill, including seabirds and forage species they normally consumed.

The strategy of the pelagic group is to monitor important pelagic species so that we may detect changes in response to future perturbations (Figure 1-1). Long-term and integrated monitoring will provide the critical information needed by managers in the context of a constantly changing environment.

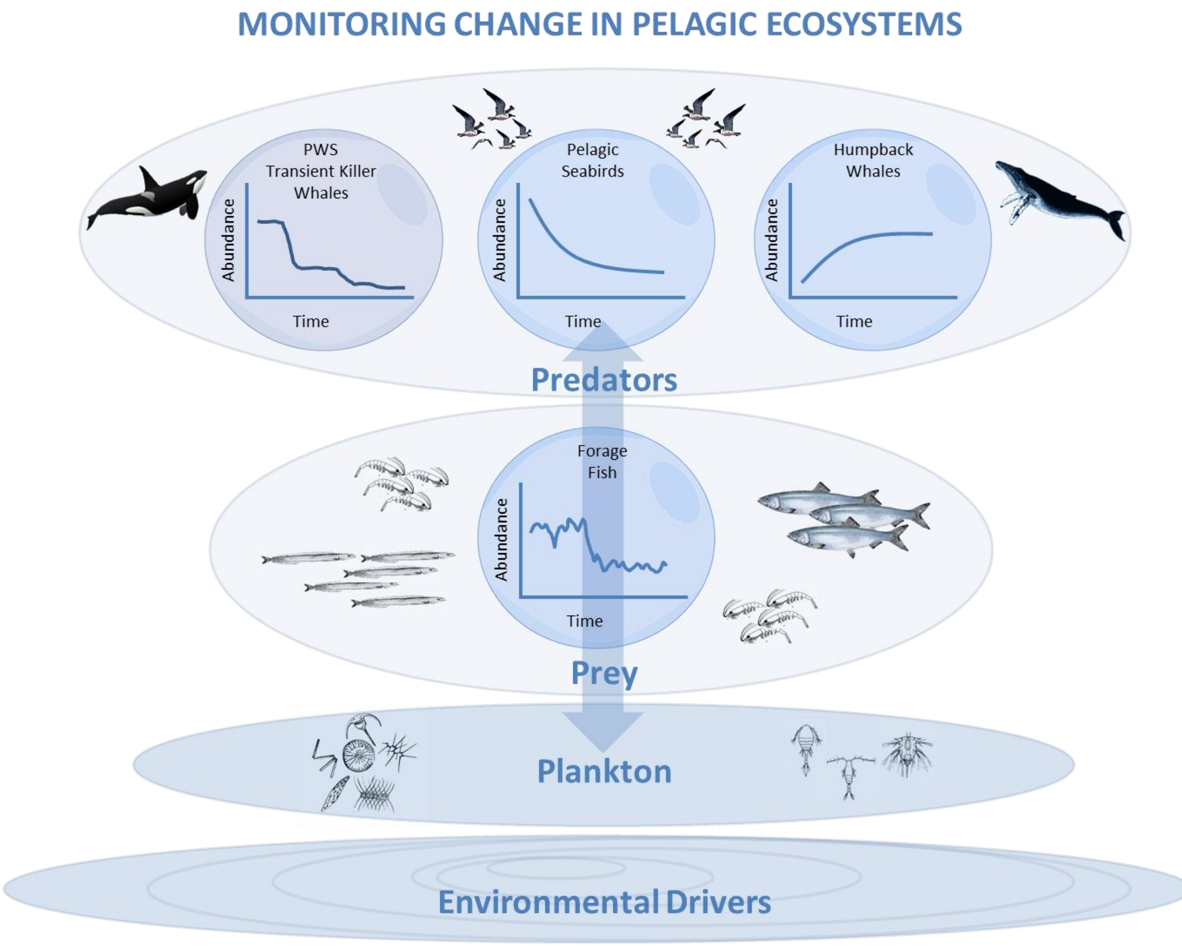

Figure 1-1 A simplified conceptual diagram of the Gulf Watch Alaska pelagic component. Data suggest that key pelagic populations respond differently to perturbations. This model recognizes the potential for top-down control within the system, as well as the more prevalent bottom-up control. The latter is derived from environmental drivers influencing primary and secondary production and thus affecting abundance and availability of middle trophic levels such as euphausiids and forage fish.

This component focuses on species that play a pivotal role in the pelagic ecosystem as trophic indicators for short and long-term ecosystem change: killer whales, humpback whales, forage fish (including euphausiids), and marine birds. The advantage of our approach is that it monitors multiple species that respond in a variety of ways to changes in the environment. For example, the three populations of killer whales in the Northern Gulf of Alaska demonstrated different responses to conditions of the past several decades. One population has declined toward extinction, the second has steadily increased, and a third has maintained a consistent level. Similarly, within the seabird community there have been major declines in pelagic species while several nearshore species have increased over the same time period. In contrast, humpback whales in the North Pacific have made a remarkable recovery since the end of commercial whaling increasing at 5-7% per year. As a large and long-lived species with high energetic demands, humpback whales may be limiting herring recovery in PWS, and thus might also be competing with marine birds for food. Linking these predatory species is a small number of forage species that play a pivotal role in the pelagic food web by transferring energy between plankton and top predators. Unfortunately there is little consistent historic information on forage fish populations.

Pelagic Chapter Articles

This chapter focuses on species that play a pivotal role in the pelagic ecosystem as trophic indicators for short and long-term ecosystem change: killer whales, humpback whales, forage fish, and marine birds.

When possible, historic data sets have been assessed with the first three years of Gulf Watch Alaska monitoring data. The chapter includes an introduction, background, and description of the study area and seven separate articles chosen to represent the work from the projects funded under this component within Gulf Watch Alaska. The articles within this chapter are:

- Research Summary: Long-term killer whale monitoring in Prince William Sound/ Kenai Fjords
- Research Summary: Long-term Monitoring of Humpback Whale Predation on Pacific Herring
- Forage Fish Populations in Prince William Sound: Designing Efficient Monitoring Techniques to Detect Change
- Spatial and Temporal Variation in Marine Birds in the Northern Gulf of Alaska: The Value of Marine Bird Monitoring within Gulf Watch Alaska
- Nearshore Marine Bird Surveys: data synthesis, analysis and recommendations for sampling frequency and intensity to detect population trends
- Research Summary: Temporal change in a subarctic marine bird community linked to habitat and climate change
- Research Summary: Long-term monitoring of seabird abundance and habitat associations during late fall and winter in Prince William Sound

Several of the articles are summaries of papers that have been published, submitted, or are in press. In an effort to comply with potential infringement laws, publications have been summarized here, and the citation to the published work provided.

Complexities of Prince William Sound's Pelagic Ecosystem

Pelagic ecosystems of the North Pacific include multiple trophic levels and an array of hundreds of marine species, including many that are critical food for economically important predators (e.g. Pacific herring and salmon). The pelagic ecosystem of Prince William Sound (PWS) is no exception, with species spanning at least five trophic levels (Okey and Wright 2004) and linked in a complex food web. In the context of Gulf Watch Alaska, other chapters have discussed elements strategically linked to pelagic ecosystems detailing conceptual models, characteristics of environmental drivers, and nearshore ecosystems.

In the Gulf of Alaska (GOA), ecosystem models have shown that no single main driver of the ecosystem can explain all species dynamics simultaneously (Gaichas et al. 2011). However in PWS there are some general characteristics that shape the pelagic elements of the ecosystem and the variability therein. Physical processes in PWS include wind, convective currents, temperatures, upwelling, nutrients, and freshwater inputs, and all contribute to high inter-annual variability in productivity (Weingartner 2007). Many of these processes have been shown to be intimately connected to the GOA (Mundy 2005, Spies 2007). This variability in productivity directly affects predator-prey relationships in PWS: resident killer whales prey on salmon that rely on zooplankton and other forage fish including herring (Matkin et al 2014); humpback whales prey on euphausiids (krill) and Pacific herring; and forage fish feed on zooplankton but are also prey for marine birds (Bishop et al. 2015; summary in this document), larger fish (Bishop and Powers 2013), and marine mammals. These bottom-up and top-down trophic relationships work in concert with each other and rely on critical timing, duration, and density of aggregating forage species for success (Spies and Cooney 2007). Population changes in any one of the pelagic species can lead to trophic cascades throughout the food web (Heithaus et al. 2008) which can result in catastrophic shifts in community structure (Fauchald 2010).

Event driven variability - PWS was generally thought of as a stable and productive environment until the *Exxon Valdez* oil spill in 1989 (EVOS). Unexpected results of the spill were persistence of oil, chronic exposure to oil for certain species, and cascades of indirect effects at the population level (Peterson et al. 2003a). Due to the lack of pre-spill baseline data, the spill provided a unique opportunity for researchers to learn about various species, understand the mechanisms of their injury, and in some cases follow their long-term road to recovery (e.g. sea otters) (Ballachey et al. 2014). Injury from the spill had significant effects on pelagic populations in PWS as well. An extreme result of the spill may be the unprecedented extinction of a unique apex predator population, the AT1killer whales (Matkin et al. 2012a), with unknown cascading effects at lesser trophic levels. The collapse of the Pacific herring population in in PWS has been ascribed to the oil spill (Thorne and Thomas 2007), but this conclusion has been hotly debated (Pearson et al. 2011). At least one marine bird, the pigeon guillemot, was heavily impacted by the spill (Golet et al. 2002) and its population in PWS has yet to recover (Cushing et al., this report). The signs of recovery for many impacted species have been obscured by other forces in the ecosystem (e.g. natural long-term cycles affecting marine bird and forage fish population trends) masking a full understanding of the ecosystem level effects. Because of a lack of pre-spill monitoring, in many cases these effects could not be separated from those of the spill. Tracking effects from the EVOS will be become more difficult as we move further away in time from the initial event.

Regime-driven variability – Natural cycles in the ecosystem can affect pelagic population trends. We recognize that multiple large-scale drivers and forces are capable of causing long-term ecosystem change in PWS. Decadal scale data have increased our awareness and understanding of drivers such as the Pacific Decadal Oscillation (PDO), El Niño/Southern Oscillation (ENSO), and North Pacific Gyre Oscillation (NPGO) (Hollowed et al. 2001b), and we are just starting to consider their relations to pelagic populations in PWS. Additional forces with even greater unknowns are those associated with impending climate change (e.g. warming waters and ocean acidification, see Chapter 1, **Error! Reference source not found.**. Without monitoring of pelagic species, there will be no chance to isolate and determine effects of these changes.

Monitoring change - Understanding how short and long-term changes affect pelagic populations in PWS requires a multi-pronged approach. First and foremost, long-term population level data sets are an essential foundation for ecosystem monitoring. Second, further development of conceptual and numerical sub-models centered on pelagic ecosystems (top-down control with humpback whale and marine bird predation, bottom-up with environmental forcing on plankton, with forage fish abundance the ecological linchpin) will be an important tool for understanding long-term changes. Over-arching hypotheses such as match-mismatch, physiological performance-temperature mediated survival, and on-shelf/off-shelf productivity will need to be considered. The key for pelagic ecosystem researchers will be to identify change, relate the change to environmental characteristics, and ultimately model the impacts of that change.

Background

The pelagic component research team identified two primary questions that could be answered with data collected and compiled under the first five years of Gulf Watch Alaska: a) What are the population trends of key pelagic species groups - whales, forage fish, and marine birds, and b) How can forage fish population trends in PWS be effectively monitored? The rationale for these goals lies with the advantage of existing long-term data sets and knowledge gained in the course of EVOS studies during the last 25 years. The pelagic team has been continuing two of the longest population time series in PWS, on killer whales and marine birds, providing invaluable insight into their dynamics. The EVOS also increased awareness of what is not understood about the pelagic ecosystem, such as variability in forage fish populations (Rice et al. 2007).

The Pelagic component of Gulf Watch Alaska encompasses six projects focused on collecting long-term predator and prey species data from sites centered in PWS. The species covered include killer whales, humpback whales, forage fish, and marine birds. The following gives a brief background on each of the focal species or species groups.

Killer whales (1 project) – Monitoring of killer whales in PWS started in 1984 and provided a high quality data set allowing for detection of injury from the EVOS at the pod and population level. This clearly illustrated the value in long-term monitoring prior to possible perturbations. Both resident ecotype (AB pod) and transient ecotype (AT1 population) killer whales suffered significant mortalities following the EVOS. AB pod is slowly recovering after 22 years but the remaining matrilines in the pod have not reached pre-spill numbers. The AT1 population is not recovering and may be headed toward extinction (Matkin et al. 2012a). This research has determined that killer whales are sensitive to perturbations such as oil spills, but as yet, has not documented the long-term consequence (extinction) or the recovery period required for AB pod. As apex predators of fish, particularly salmon, (resident ecotype whales) and other marine mammals (transient whales), killer whales can significantly affect upper trophic dynamics and are a key species for monitoring the pelagic ecosystem. Since killer whales are long lived and slow to reproduce, they reflect long-term trends in the ecosystem as well as being susceptible to immediate perturbations.

Humpback whales (1 project) –. In 1946, the International Convention for the Regulation of Whaling regulated commercial whaling of humpback whales. In 1966, the International Whaling Commission prohibited commercial whaling of humpbacks. In June 1970, humpback whales were designated as "Endangered" under the Endangered Species Conservation Act (ESCA). In 1973, the Endangered Species Act (ESA) replaced the ESCA, and continued to list humpbacks as endangered. The Central North Pacific and North Pacific stocks of humpback whales are currently listed as Endangered under the Endangered Species Act, but populations are rebounding and have been steadily increasing in PWS since the end of industrial whaling. Currently there is a petition to de-list humpback whales from the endangered species list. The North Pacific population is now thought to be increasing 5-7% annually (Barlow et al. 2011). Consistent with this increase, the numbers of humpback whales in PWS in summer has increased at about the same rate since the 1980s (Teerlink et al. 2014). Continued monitoring of this predator-prey relationship is an integral piece of the trophic puzzle in PWS.

Forage fish (1 project) – This component focuses on euphausiids, herring, capelin, eulachon, Pacific sand lance, juvenile pollock and juvenile pollock. Because most these species have no direct commercial value there are few data on their abundance or distribution. However, fluctuations in forage fish abundance can have dramatic ecosystem effects because much of the energy transferred from lower to higher trophic levels passes through a small number of key forage fish species in PWS (Okey and Wright 2004, Springer 2007). This species group has long been noted as an important component of the ecosystem food web, critical to other species (marine birds, larger fish, and marine mammals) (Pikitch et al. 2014). Information is needed on their biology, essential habitats, and population dynamics. Knowing habitats that fish use throughout their life history is paramount before we can begin to understand how biophysical forces will affect their populations. The life history complexities of forage fish, along with minimal baseline data available at the population level, require establishing sampling protocols that provide accurate and precise data and can be repeated as a monitoring tool in the future. Hence, this effort was identified as one of the key goals of the pelagic group.

Marine Birds (3 projects) – There has been long-term monitoring of marine bird populations in PWS since the onset of the EVOS in 1989. An estimated 250,000 marine birds were killed during the EVOS in PWS and the northern Gulf of Alaska (Piatt and Ford 1996). Data collected from 1989 to 2010 indicated that pigeon guillemots (*Cepphus columba*) and marbled murrelets (*Brachyramphus marmoratus*) were declining in the oiled areas of PWS (Piatt and Ford 1996, Rice et al. 2007) (Piatt and Ford 1996, Rice et al. 2007), and recent surveys found continued decline or possible stabilization at much lower population sizes (Kuletz et al. 2011, Cushing et al., this report). The primary GWA project monitoring marine birds in PWS is conducted during July, and maintains protocols of the historic data set. In addition to these continued monitoring surveys, researchers are using the long-term data set to examine temporal changes in the marine bird community linked to habitat and climate change. These surveys are among the longest time series available for PWS and offer the most sensitive vehicle to track biological response to environmental change over time.

A second complementary project is focused on monitoring marine birds in PWS from late fall through the winter, the period during which birds face the greatest environmental pressures. Initiated in 2007, this monitoring program places a marine bird observer on regularly scheduled cruises associated with various projects in PWS (EVOS herring and Gulf Watch Alaska humpback whale studies, as well as ADFG shrimp surveys, and Ocean Tracking Network array maintenance). The surveys use USFWS protocols and cover all marine habitats in PWS (bays, passages, and open water). Most marine bird studies occur during summer months, therefore little is known about the habitat associations during winter. Long-term monitoring of marine birds in PWS during winter is needed to understand how changing biophysical factors are affecting spatial and temporal trends in bird abundance, species composition and habitat use. A third project focuses on birds foraging near the shoreline, an often neglected group of predators for pelagic and benthic ecosystems. These nearshore marine birds include black oystercatchers (*Haematopus bachmani*), cormorants (*Phalacrocorax* spp.), glaucous-winged gulls (*Larus glaucescens*), goldeneyes (*Bucephala* spp.), harlequin ducks (*Histrionicus histrionicus*), mergansers (*Mergus* spp.), pigeon guillemots (*Cepphus columba*), and scoters (*Melanitta* spp.). Several agencies have been conducting skiff based surveys for marine birds in the shallow nearshore waters along Katmai, Kenai Fjords, and PWS coastlines ranging from 5 to 20 years (Bennett et al. 2006a). The goal is to continue monitoring existing transects that have continuity with legacy data and work on examining the effects of sampling error and imperfect detection. Another goal is to make recommendations for improving efficiency through sample intensity and frequency.

Pelagic Recommendations

Continue to characterize long-term variability and population trends for all pelagic species being monitored:

- Killer whale population monitoring to determine required time for their recovery and possible extinction due to the oil spill.
- Humpback whale population trend and abundance information in PWS to understand top-down predation on herring and a changing prey field.
- Monitor forage fish as a key component of pelagic ecosystems.
- Seasonal surveys of marine seabirds in PWS and in conjunction with environmental driver component efforts in the Northern GOA (e.g., Seward Line, LCI surveys).

Recommendations for enhancement of current monitoring projects

There are gaps in the current information that would be addressed through further monitoring and process studies that are currently not funded within this program. Current monitoring work leveraged with other studies and technologies has the potential for broader ecological studies that will draw connections between individual species as well as the components of this study

- *Killer whales and humpback whales* - conduct supplemental monitoring with additional focus on feeding ecology using tagging, tissue sampling, and prey sample collection to better inform fisheries managers on consumption rates by large apex predators.
- Integrate existing data from outside this program for other pelagic predator/prey species, including harbor seals, Steller sea lions, and salmon.
- *Forage fish* - due to the nearshore, shallow, and patchy distribution of forage species in the Sound during summer, broad-scale systematic hydroacoustic-trawl surveys for forage fish are not effective or cost efficient. We suggest the following:
    - In addition to aerial shoreline surveys and a validation component with Herring Research and Monitoring program, include acoustic-trawl measurements of prey composition, density, and depth distribution near foraging predators to measure direct linkages to whales and seabird predators (see hotspots below).
    - Support the longest time-series of seabird diet available for the region (i.e., Institute for Seabird Research and Conservation -- Middleton Island) as a forage fish index in the Gulf of Alaska region (Hatch 2013). The continuation of this dataset will be important for

informing other ecosystem components with a shorter monitoring history.

- *Integrated hotspot monitoring* - characterize multi-species predator prey aggregations. We have identified a few key areas where pelagic components overlap in time and space, (one example, Montague Strait during September). Integrate environmental conditions into this monitoring.
- Because of evidence for large scale movements of pelagic predators in and out of PWS, expand the scope of pelagic components to other regions of the Northern GOA. This would align our component spatially with other Gulf Watch Alaska components to produce a more complete picture, e.g., repeat EVOSTC work in Cook Inlet, initiate seabird and humpback whale surveys on the GOA shelf (leveraging collaboration with NOAA fisheries stock assessment surveys or continued collaboration with the Seward Line and LCI programs).

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