Exxon Valdez Oil Spill
Long-Term Monitoring Program (Gulf Watch Alaska) Final Report

Long-term killer whale monitoring in Prince William Sound / Kenai Fjords
Exxon Valdez Oil Spill Trustee Council Project 21120114-N
Final Report

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August 2023

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Study History: The North Gulf Oceanic Society independently maintained a monitoring program for killer whales (*Orcinus orca*) in Prince William Sound from 1984-1988 (Matkin et. al. 1994). This work was partially funded by a variety of non-profit foundations and government grants. Following the *Exxon Valdez* oil spill in 1989, killer whales were monitored in Prince William Sound with funding from the *Exxon Valdez* Oil Spill Trustee Council in 1989, 1990, and 1991 (Dahlheim and Matkin 1993) and in 1993 (Dahlheim 1994). The North Gulf Oceanic Society independently maintained a monitoring program in 1994. An assessment of the status of killer whales from 1984 to 1992 in Prince William Sound was published by Matkin et al. in 1994.

The current study builds upon this historical work as well as the other *Exxon Valdez* Oil Spill Trustee Council-supported projects listed below. The final reports for these projects are available from the Alaska Resources Library and Information Services or from the North Gulf Oceanic Society as:

Matkin, C. O., G. Ellis, L. Barrett Lennard, H. Yurk, E. Saulitis, D. Scheel, P. Olesiuk, and G. Ylitalo. 2003. Comprehensive killer whale investigation. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 00112), North Gulf Oceanic Society, Homer, Alaska.

Matkin, C. O., G. Ellis, E. Saulitis, D. Herman, R. Andrews, A. Gaylord, and H. Yurk. 2010. Monitoring, tagging, remote acoustics, feeding habits, and restoration of killer whales in Prince William Sound/Kenai Fjords 2003-2009. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 090742). North Gulf Oceanic Society, Homer, Alaska 99603

Matkin, C. O., G. Ellis, E. Saulitis, D. Herman, R. Andrews, and A. Gaylord. 2013. Monitoring, tagging, feeding habits, and restoration of killer whales in Prince William Sound/Kenai Fjords 2010-2012. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 10100742). North Gulf Oceanic Society, Homer, Alaska 99603.

Matkin, C. O., D. W. Olsen, G. Ellis, G. Ylitalo, and R. Andrews 2018. Long-term killer whale monitoring in Prince William Sound / Kenai Fjords. Long-Term Monitoring Program (Gulf Watch Alaska) Final Report (*Exxon Valdez* Oil Spill Trustee Council Project 16120114-M). *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska.

Abstract: Pre-spill photo-identification studies initiated in 1984 made possible assessment of changes in killer whale populations following the *Exxon Valdez* oil spill. Here we report on status of strategic killer whale groups in the 2017-2021 reporting period. Both the resident AB pod and the AT1 transient population suffered significant losses following the spill and neither has recovered. After declining from 26 to 16 whales following the oil spill, AB pod had been slowly recovering to a post-spill high of 22 whales in 2015. However, AB pod declined in this reporting period from 22 whales in 2015 to just 14 whales in 2017, increasing to 17 in 2021. This latest decline came at the end of a marine heatwave during 2014-2016 that has had acute and prolonged impacts on the Gulf of Alaska ecosystem and apparently erased 30 years of post-spill recovery of AB pod. This decline in abundance of AB pod, and similar declines in other AB clan pods, demonstrates the need for continued monitoring to understand how environmental variation will affect recovery potential. The AT1 population numbered 22 animals prior to the spill and remained constant at seven individuals throughout this reporting period. It is headed toward extinction because the four remaining females are likely beyond reproductive ages. Analysis of killer whale feces and scale samples from prey indicated that Southern Alaska Residents have a diverse summer (May-September) diet with a preference for chum and Chinook salmon, coho salmon increasing in late season, and including halibut, arrowtooth flounder and sablefish. The attached published paper describes the distribution and occupancy patterns of three killer whale populations (southern Alaska residents, Gulf of Alaska transients, and AT1 transients) from passive acoustic monitoring. The highest year-round acoustic presence occurred in Montague Strait, with strong seasonal patterns in Hinchinbrook Entrance and Resurrection Bay. Drone photogrammetry was found to be a feasible and powerful method for quantifying nutritional health and will be routinely used in future years.

Key words: Acoustics, feeding habits, killer whale (*Orcinus orca*), photogrammetry, population dynamics, resident, transient.

Project Data: All required datasets have been updated on the Gulf of Alaska Data Portal (https://portal.aoos.org/gulf-of-alaska#metadata/2f42dd1c-d67a-4c49-8c2e-1d63387e0ad0/project/files). The photographic and Soundtrap acoustic files are very large and cannot be uploaded and accessed with a browser easily, and we supplied the data to Axiom Data Science via a hard drive. Data through August 2020 will be supplied by May 2021. Currently, data from 2012-2019 (Gulf Watch Alaska period) have been published by Axiom, which include the following:

- Shipboard acoustic recordings, 2012-2019 (https://portal.aoos.org/gulf-of-alaska#metadata/2f42dd1c-d67a-4c49-8c2e-1d63387e0ad0/project/folder_metadata/2689596)
- Biopsy data, 1994-2019, including results of chemical tracer analysis (https://portal.aoos.org/gulf-of-alaska#metadata/2f42dd1c-d67a-4c49-8c2e-1d63387e0ad0/project/folder_metadata/24158)
- Database of surveys and encounters, 2001-2019 (includes Access database: https://workspace.aoos.org/project/4682/folder/2824129/database-of-surveys-and-encounters-2017-2021)

- Prey sampling, 1991-2018 (https://workspace.aoos.org/project/4682/folder/2529812/prey-genetics)

- Soundtrap (remote hydrophone) data through 2019 have been delivered to Axiom for publication (https://portal.aoos.org/gulf-of-alaska#metadata/2f42dd1c-d67a-4c49-8c2e-1d63387e0ad0/project/folder_metadata/2689596)

- Field identification photos through 2019 were posted by Axiom to a separate site on the Research Workspace because of their large size (https://portal.aoos.org/gulf-of-alaska#metadata/2f42dd1c-d67a-4c49-8c2e-1d63387e0ad0/project/folder_metadata/2689692)

- The annotated passive acoustic monitoring dataset used in this study is available at https://seamap.env.duke.edu/dataset/2158

Discussions are underway within Axiom to determine how to deal with large datasets that currently are impractical to access through a browser. Please contact the data custodian for assistance.

The data custodian is Carol Janzen, Director of Operations and Development, Alaska Ocean Observing System, 1007 W. 3rd Ave. #100, Anchorage, AK 99501, 907-644-6703. janzen@aoos.org.

Data are archived by Axiom Data Science, a Tetra Tech Company, 1016 W. 6th Ave., Anchorage, AK 99501.

Citation:

Matkin, C. O., J. Durban, D. Olsen, H. Myers, and G. Ellis. 2023. Long-term killer whale monitoring in Prince William Sound/ Kenai Fjords. *Exxon Valdez* Oil Spill Long-term Monitoring Program (Gulf Watch Alaska) Final Report (*Exxon Valdez* Oil Spill Trustee Council Project 21120114-N), *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska.

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Long-term killer whale monitoring in Prince William Sound / Kenai Fjords

EXECUTIVE SUMMARY

Population monitoring of killer whales (*Orcinus orca*) in Prince William Sound and Kenai Fjords, Alaska, has occurred annually since 1984. This report covers the five-year period from 2017-2021. We focused on two groups of killer whales of strategic interest because they were directly injured by the *Exxon Valdez* oil spill: the AT1 population of transients and the AB pod of residents. To provide a comparative context for assessing recovery, we also monitor other pods within the southern Alaska resident population, of which AB pod is part. In the current study period, a total of 310 survey days were spent on the water between May 1 and October 30 across the five years. There were 185 encounters with resident killer whales and 15 encounters with AT1 transients.

After declining from 26 to 16 whales following the oil spill, AB pod had been slowly recovering to a post-spill high of 22 whales in 2015. However, AB pod declined in this reporting period from 22 whales in 2015 to just 14 whales in 2017, increasing to 17 in 2021. This latest decline came at the end of a marine heatwave during 2014-2016 that has had acute and prolonged impacts on the Gulf of Alaska ecosystem and apparently erased 30 years of post-spill recovery of AB pod.

AB pod is part of the larger AB acoustic clan of residents. The AB clan declined by 2% in combined abundance during the reporting period, further suggesting that these pods were affected by ecosystem impacts during and after the marine heatwave, and reinforcing the need for continued monitoring to understand how environmental variation has and will affect recovery potential. In contrast, the abundance of index pods in the inshore-tending AD acoustic clan increased by 18% over the reporting period, raising questions about the ecological variation within the Alaska resident population and its vulnerability to warming ocean conditions.

The AT1 population has remained constant at seven individuals, with no mortality or recruitment during the reporting period; this remains below their pre-spill high of 22 individuals. The population is headed toward extinction because the four remaining females are likely beyond reproductive ages.

The assessment of diet for resident killer whales is important for understanding population dynamics in the context of ecosystem changes in lower trophic levels. We collected and analyzed 257 samples of fish scales or flesh from feeding events during 1991-2021, and 86 fecal samples from killer whales during 2017-2021. Between both data sets, samples contained chum, Chinook, coho and smaller quantities of sockeye salmon, as well as Pacific halibut, Arrowtooth flounder, sablefish. In early season Prince William Sound (June and July), both datasets were dominated by chum salmon. In early season Kenai Fjords (May and June), both datasets were dominated by Chinook salmon. In late season (August and September), coho dominated the scale/flesh dataset

but no single species was dominant in the late season fecal data, which showed increased diversity. Neither pink salmon nor herring were found in percentages exceeding 0.1%, and likely were only secondary prey, having themselves been consumed by the primary prey species for killer whales. As sample sizes increase, we will investigate pod-specific differences in diet and how these related to differences in population dynamics.

We successfully tested the use of drones for obtaining images suitable for photogrammetry measurements of health metrics. This approach will now be used routinely to better understand nutritional health and the ecological factors affecting pod-specific population dynamics. We flew 22 successful drone flights over four days in 2021, collecting 17,822 aerial images of two pods of resident killer whales. We compiled an aerial catalog that distinguished all members of the AK02 and AD08 pods (30 individuals total). We collected an average of 34 measurement-quality images of each whale that will be used to quantity body condition and monitor growth through length-at-age relationships.

We examined the year-round distribution of killer whales in the northern Gulf of Alaska from 2017 to 2020 using passive acoustic recordings from mooring in Kenai Fjords (Resurrection Bay) and moorings in two entrances to Prince William Sound (Hinchinbrook Entrance and Montague Strait). For all years, the highest year-round acoustic presence occurred in Montague Strait, with strong seasonal patterns in Hinchinbrook Entrance and Resurrection Bay. Daily acoustic residency times for the southern Alaska residents paralleled seasonal distribution patterns. The majority of Gulf of Alaska transient detections occurred in Hinchinbrook Entrance in spring. The depleted AT1 transient killer whale population was most often identified in Montague Strait. Both resident and transient killer whales used these areas much more extensively than previously known and provided novel insights into high use locations and times for each population. These results may be driven by seasonal foraging opportunities and social factors and have management implications for this species.

INTRODUCTION

Population monitoring of killer whales (*Orcinus orca*) in Prince William Sound and Kenai Fjords, Alaska, has occurred annually since 1984. The existence of data prior to the *Exxon Valdez* oil spill in 1989 made it possible to determine that both whales of the resident ecotype, AB pod, and whales of the transient ecotype, the AT1 population, suffered significant mortalities following the spill (Matkin et al. 2008). The AB pod was recovering slowly until a decline during this reporting period and has still not reached pre-spill numbers. The AT1 population is not recovering and may be headed toward extinction. This project has determined that killer whales are sensitive to perturbations such as oil spills, but has not yet determined the ultimate long-term consequence (which may include extinction) or the recovery period required after such a perturbation. Ecosystem changes may also complicate aspects of recovery, hence our investigation in this report of the impact of the 2014-2016 marine heatwave.

During the last five years, this project continued using photo-identification methods to monitor changes in resident killer whale pods, including AB pod, and the AT1 transient population. We also monitored 10 regularly sighted resident "index" pods to provide a comparative context for population dynamics in a changing ecosystem. Specifically, the Gulf of Alaska was impacted by an intense marine heatwave in 2014-2016, which has had prolonged ecosystem effects (Suryan et al. 2021). Here we demonstrate that these effects have propagated to the top of the marine food chain to impact killer whales. A journal paper detailing the population dynamics of resident killer whales in the northern Gulf of Alaska was published during the previous funding cycle (Matkin et al. 2014) and another detailing the impacts of the marine heatwave is in preparation and progress summarized here.

In addition to photo-identification for abundance monitoring, we used prey sampling, killer whale fecal sampling and passive acoustic monitoring to study feeding ecology and distribution, respectively. This information will enable killer whale population dynamics to be interpreted in an ecosystem context, and data on diet is clearly important to help understand bottom-up ecosystem effects (Ford et al. 2010). It is a common perception that resident killer whales in the North Pacific primarily feed on Chinook salmon (*Oncorhynchus tshawytscha*) in part due to the large number of publications and research regarding the endangered Southern Resident killer whale population off Washington State (e.g. Hanson et al. 2010). A preference for Chinook salmon has also been shown in Northern resident killer whales in British Columbia (Ford and Ellis 2006). In fact, it has even been suggested that the selective removal of large Chinook by killer whales has likely contributed to the apparent widespread declines in average Chinook body size (Ohlberger et al. 2018). As such, our updated assessment of the diet of southern Alaska resident killer whales is also important for understanding top-down impacts of these top predators on lower trophic levels, including Chinook salmon, by providing more detail on the extent of selection due to dietary preferences.

We also conducted a successful feasibility study using drone-derived images to collect photogrammetry measurements to infer nutritional health. Routine application in future years can provide both short-term (body condition) and longer-term (growth) data on responses to ecosystem changes to further help diagnose the causes of population dynamics. In the shorter term, this new element to our research will provide data to compare the nutritional health of southern Alaska resident killer whales to killer whales in other regions where photogrammetry studies are established (e.g. Durban et al. 2015, Stewart et al. 2021).

OBJECTIVES

1. Photo-identify all major resident pods and AT1 transient groups that use Prince William Sound/Kenai Fjords on an annual basis. In practice, all pods are completely documented only on a biennial basis, despite annual field effort. Extension of individual histories, identification catalogues of individuals and an annual update of pod abundances are products of these data (**Core Objective**).

2. Collect killer whale feces during focal follows and subsequent genetic analysis of prey content to compare with samples obtained in objective 3. Fecal collections replace originally proposed blubber analysis for food habits. Analytical costs borne by the National Oceanic and Atmospheric Administration Northwest Fisheries Science Center and an external grant from National Fish and Wildlife Foundation (**Core Objective)**.
3. Collect fish scale samples and marine mammal tissue from kill sites to monitor potential changes in feeding habits. **(Core Objective)**. Analytical costs were borne by Pacific Biological Station, Nanaimo, British Columbia.
4. Using autonomous recording hydrophones (Ocean Instruments SoundTrap), track killer whales using calls. The hydrophones provided continuing data on use patterns information for areas already identified as most important for killer whales using tagging and encounter data during previous work (**Core objective**).
5. Collect genetic tissue samples when necessary to determine population/ecotype affiliations (**Core objective**).
6. Use photogrammetry to develop morphometrics for individuals and groups to assess body condition over time and develop measures to determine pregnancy rate as an additional important population parameter (**secondary objective, completed as possible**).
7. Use time/depth/location satellite tags coupled with prey sampling to examine feeding ecology during fall and/or spring feeding aggregations (**not conducted due to animal welfare concerns)**.

METHODS

The vessel surveys conducted in this project focused on the bays and passes of Prince William Sound and the Kenai Fjords region and particularly the ocean entrances (Fig. 1). These waters are glacially carved and relatively deep (300-500 m), and experience strong tidal currents (Halverson et al. 2013). Strong downwelling conditions in winter promote inflow into Prince William Sound through Hinchinbrook Entrance and outflow through Montague Strait, but this pattern is less distinct in the summer months as offshore downwelling conditions relax (Halverson et al. 2013).

Data collection

Fieldwork during the 2017-21 study period was completed from the *R/V Natoa,* a 10.3 m inboard diesel-powered vessel, capable of 12 knots and sleeping up to four researchers.

We based field timing and search locations on current and historical sighting information to maximize the number of killer whale encounters. This information included passive acoustic detections (objective 4) and satellite tag data (Olsen et al. 2018). Consequently, searches were centered in areas with historically high encounter rates with killer whales, unless sighting or detection information indicated changes in whale distribution. Whales were found visually, by listening for killer whale calls with a directional hydrophone, or by responding to VHF radio calls from other vessel operators. Regular requests for recent killer whale sightings were made on hailing Channel 16 VHF. In Kenai Fjords, Channel 71, the tour boat channel, was also monitored. An encounter was defined as the successful detection, approach and taking of identification photographs of killer whales. Reports from other mariners (generally by VHF radio) were used to select areas to be searched. All identifications were made from photographs taken during encounters or provided on our website by other mariners if of sufficient quality and accompanied by appropriate data.

Objective 1: Photographs for individual identification were taken of the left side of each whale showing details of the dorsal fin and saddle patch. Digital images were taken at no less than 1/1000 sec shutter speed using a Nikon D-700 or D-750 camera and a 300 mm f4.5 auto focus lens. When whales were encountered, researchers systematically moved from one subgroup (or individual) to the next keeping track of the whales photographed. If possible, individual whales were photographed several times during each encounter to ensure an adequate identification photograph. Whales were followed until all whales were photographed or until weather and/or darkness made photography impractical.

A vessel log and chart of the vessel track were kept for each day the research vessel operated using a Garmin GPS V that was downloaded each evening. Track lines were then converted to GIS shapefiles using Minnesota DNR Garmin 5.4 software. Similar logs were kept for all previous study years and stored as shapefiles with encounter tracks separated from overall vessel tracks and used to estimate sampling effort (Scheel et al. 2001). On daily logs, the elapsed time and distance traveled were independently recorded. Weather and sea state as it affected daily surveys was noted.

Specifics of each encounter with killer whales were recorded on standardized data forms originally developed in 1984. These forms have been updated periodically to reflect changes in data collection needs and emphasis (most recently modified in 2016). Data recorded included date, time, duration, and location of the encounter. References to digital photographic files were created and the estimated number of whales photographed also were recorded. Specific group and individual behaviors (i.e., feeding, resting, traveling, socializing, milling) were recorded by time and location. Directed observations of feeding behavior and identification and collection of killer whale prey and fecal material were made when possible.

Objective 2: Free-floating killer whale feces were also collected, and genetic analysis of prey species completed at the National Oceanic and Atmospheric Administration Northwest Fisheries Science Center, Seattle, Washington by Drs. Kim Parsons and Amy van Cise. Killer whale feces were collected with a fine mesh net using an extendable handle (4 m maximum extension). The net was rinsed thoroughly and sprayed with dilute bleach solution between samples to prevent genetic contamination. The pod or group of killer whales and specific individuals present being tracked when feces were collected were identified and recorded on the encounter data sheets.

Marine mammal kills were confirmed by the observation of marine mammal parts in the mouths of the transient whales, or marine mammal tissue (bits of blubber, skin, viscera, hair, blood or oil) in the water in the vicinity of the whales. The species identity of marine mammal prey was usually determined during observations of attacks and chases. Harassment of prey was considered to have occurred when potential prey animals exhibited an avoidance or alarm response in the presence of nearby killer whales or when killer whales chased, followed or lunged at potential prey without making a kill, or when, following an attack, a kill was suspected but could not be confirmed.

Objective 3: Fish scales or pieces of flesh from prey were collected using an extendable, fine-mesh dip net following visually detected resident killer whale predation events. Sampling of prey remains occurred opportunistically during the period of our annual photo-census (May-September) and generated data on both prey species identification as well as prey life history data as determined from scale annuli. Scales were aged and identified at the Pacific Biological Station, Nanaimo, British Columbia by making acetate impressions and viewing the impressions on a Neopromar projecting scope. Magnifications of 10x to100x were used in the analysis (MacLellan 2004). Sampling of prey was coupled with standard killer whale photo-identification procedures (Objective 1; detailed in Bigg et al. 1990 and Matkin et al. 1999) to determine the identity of the population, the pod, and, in some cases, the individual whale, using existing photographic catalogues (Matkin et al. 1999).

Predation events by resident (fish eating) killer whales were initially identified acoustically by the presence of echolocation clicks and discrete calls detected using an Offshore Acoustics omni-directional hydrophone (100Hz to 25 kHz). In addition, there were visual cues such as erratic movements of widely spaced individuals. As in our previous study (Saulitis et al. 2000), predation events accompanied by noticeable whale surface activity typically triggered our movement to the kill site and the attempted collection of scale samples. We also were successful in obtaining scale samples by following an individual (or cow/calf pairs) for extended periods during foraging and waiting for successful feeding to occur. However, subsurface prey captures are not always accompanied by obvious surface activity, although the whale may occasionally carry prey to the surface. This made extended follows of individuals more productive at times than searching for obvious surface kills.

Objective 4: We placed Ocean Systems "Sound Trap" autonomous recorders in 32-45 m of water in three locations: Entrance to Resurrection Bay, Lower Montague Strait, and Hinchinbrook Entrance. All three areas were known to be important for killer whales at least seasonally from earlier telemetry data. The year-round recordings would facilitate examining year-round patterns of use which was not possible with shorter term telemetry.

Objective 5: Biopsy samples that were collected in previous funding cycles were used to determine ecotype and population affiliation of new individuals using their association with sampled individuals as criteria for population affiliation. Biopsy samples were collected using a pneumatic rifle and custom-designed biopsy darts (Barrett-Lennard et. al. 1996). A small dart was fired from a specially outfitted rifle powered by air pressure from a .22 caliber blank cartridge. A lightweight plastic and aluminum dart (approximately 10 cm long by 1.2 cm diameter) was fitted with a beveled tubular sterile stainless-steel tip that took a small core of skin and blubber (approximately 1.6 cm long and 0.5 cm diameter). The sterilized dart was fired from a range of 16-20 m. The dart struck the animal in the upper back, excised a small tissue sample, bounced clear of the whale, and floated with the sample contained until retrieved with long handled net. Additional sampling was unnecessary during the FY17-21 period to meet objective 5 because observations of association with previously sampled and genotyped individuals were successful in confirming population affiliations.

Objective 6: In the final year of this reporting period, we assessed the feasibility of using of drone photogrammetry to measure individual killer whale morphology. This element will be developed for the Gulf of Alaska to allow investigation of the health changes underpinning population dynamics. Studies of Southern Resident killer whales off Washington State have demonstrated that health metrics can provide sensitive population indicators, providing quantitative measures for large numbers of individuals that expand population data on births and deaths to provide greater power for detecting trends and environmental covariates (Stewart et al. 2021).

Aerial (overhead) images of killer whales were collected from a drone (an octocopter, 36” across APO-36, Aerial Imaging Solutions) operated by a uniquely experienced flight team (Dr. John Durban and Dr. Holly Fearnbach). The drone was deployed and retrieved by hand from the deck of the R/V *Natoa*, utilizing the aircraft’s vertical takeoff and landing capability. The drone was equipped with a digital camera and Normal lens to capture flat images with no wide-angle distortion and water-level pixel resolution of <1.5 cm (Durban et al. 2021). The camera was mounted in a powered gimbal to maintain vertical orientation, and a precise laser altimeter (<0.1% error) was mounted on the same gimbal to enable measurements in pixels to be scaled to real size (e.g., Groskreutz et al. 2019). When whales surfaced in the frame, the pilot remotely triggered the camera to record high-resolution still photographs at one-second intervals to maximize the chance of obtaining “flat” images for unbiased photogrammetry measurements. The support boat was repositioned during flights to maintain a consistent and non-invasive contact distance.

Analytical methodology

Objective 1: Digital images were examined using PhotoMechanic software (CameraBits Inc.) on an Apple computer with a 24-inch, high resolution LCD screen. Identifiable individuals in each image were recorded. When identifications were not certain, they were not included in the analysis. Unusual wounds or other injuries were noted. The alphanumeric code used to label each individual was based on Leatherwood et al. (1990) and Heise et al. (1992) and has been continued in the catalogue of southern Alaska killer whales (Matkin et al. 1999). More recently we have posted an updated catalogue of individuals on our website (whalesalaska.org). The first character in the code is "A" to designate Alaska, followed by a letter (A-Z) indicating the individual's pod. Individuals within the pod receive sequential numbers. For example, AB3 is the third whale designated in AB pod. New calves were identified and labeled with the next available number.

From photographic identifications, the actual number of whales identified and pods of whales present for each encounter was determined and included with each encounter summary entered in the Database of Surveys and Encounters. These and other data from this project can be found on the AOOS Ocean Workspace:
https://workspace.aoos.org/group/4601/project/4682/folder/4879/data

Objective 2: Whole genomic DNA was extracted from a pea-sized subsample of fecal matter using the Qiagen Blood and Tissue extraction kit and the QIAcube automated extraction robot. Fecal samples were stored frozen (-20°C) until DNA was extracted. Sample homogenization was not deemed necessary due to sample consistency. The 16S SSU rDNA was targeted following previously established protocols for resident killer whale prey metabarcoding (Ford et al. 2016). Polymerase chain reaction (PCR) amplifications contained 4µL of DNA, 1X Promega GoTaq Flexi buffer (Promega Corp., Madison, Wisconsin), 3.0mM $MgCl_2$, 0.2mM of each dNTP, 0.1µg/µL of BSA, 0.2µM of each primer, and 2 units of Promega GoTaq Flexi DNA Polymerase. Prey communities were amplified in a 32-cycle polymerase chain reaction (PCR), with cycling conditions as follows: initial denaturation at 94°C for 2 min, followed by 32 cycles of 94°C for 35 sec; 61°C for 1 min; 72°C for 35 sec; and a final extension at 72°C for 5 min. Amplicons were gel cleaned using Qiagen MinElute columns to remove non-target PCR products and primer dimer, uniquely indexed and sequenced on an Illumina MiSeq next generation sequencing platform. Genetic sequences from all Illumina runs were combined and analyzed using a custom pipeline based on the dada2 package (Callahan et al. 2016) in the R computing environment (R Core Team 2016). Taxonomy was assigned to prey sequences using a naïve Bayesian classifier (Wang et al. 2007) that relies on a custom-generated reference database containing published sequences (NCBI GenBank) for all fish and shark species.

Genetic sequence data were filtered to remove all sequences that assigned to *Orcinus orca* and all prey sequences were aggregated by species. Samples with a read depth < 25,000 reads were removed from the dataset. Prey species representing >1% of sequence reads in ≥ 1 sample were only included in downstream analyses if they represented >1% of the reads in 1 or more samples in the dataset, in order to avoid potential bias from sequencing error. “Major prey species” were defined as species representing >1% of the reads in 4 or more samples across the dataset, to avoid potential secondary prey items (i.e., species eaten by killer whale prey).

All data analyses were conducted in R (R Core Team, 2016) using the phyloseq (McMurdie and Holmes 2013) and vegan (Oksanen et al. 2019) packages, and graphed using ggplot (Wickham 2009). Differences in prey species composition between the two geographic regions were tested for statistical significance using PERMANOVA implemented in vegan. Within PWS, PERMANOVA was used to assess seasonal variability in fecal composition. Seasonal and regional shifts in diet proportions were examined by combining all samples from a given month or region across all years in the study.

Objective 3: Scales and flesh samples were used to identify salmon species and stock. Salmonid identifications were performed based on laboratory results as in Ford and Ellis (2005). Fish scales were analyzed by the Sclerochronology Laboratory at the Pacific Biological Station (Department of Fisheries and Oceans, Nanaimo, British Columbia) to determine species identity according to procedures outlined in MacLellan (2004). Scales that could not be positively identified to species and tissue samples collected from feeding events were submitted to the Molecular Genetics Laboratory at the Pacific Biological Station for species identification using allelic size range of genomic DNA. Variation at twelve microsatellite loci were used to identify species using a mixture analysis program. The baseline consisted of 268 populations ranging from southeast Alaska to California.

Objective 4: We analyzed data from Sound Trap recorders to determine residency patterns of killer whales in three ocean entrances in the study area. For methods, see Appendix 1: Myer et al. 2021. “Passive acoustic monitoring of killer whales (*Orcinus orca*) reveals year-round distribution and residency patterns in the Gulf of Alaska”.

Objective 5: Genetic analyses of killer whale biopsy samples used data from 26 nuclear microsatellite loci and mitochondrial DNA sequences (988 base pairs) for ecotype and population assignment (Parsons et al. 2013). Additional sampling was unnecessary during the FY17-21 period to meet objective 5 because observations of association with previously sampled and genotyped individuals were successful in confirming population affiliations.

Objective 6: Aerial images for photogrammetry measurements were were linked to whales of known identity by matching to an established photo-identification catalog (http://www.whalesalaska.org). Boat-based images were taken simultaneously with drone operations to facilitate initial identification matching and an aerial catalog of individuals was established. As the aerial dataset increases in the coming years, measurements taken will include those that will permit analysis of growth from length-at age relationships, body condition changes between years and seasons, and identification of pregnancies to track changes in reproductive success within the Southern Alaska resident killer whale population.

RESULTS

Summary of effort and encounters

During the period of this study, 2017-21, the *R/V Natoa* spent a total of 310 days on the water searching for killer whales along 24,037 km of track line for an average search distance of 77.5 km day. Killer whales were encountered on 213 occasions (Table 1, Figs. 1, 2).

Table 1. Summary of effort tracking killer whales in Prince William Sound and Kenai Fjords, Alaska.

Year	# Vessel survey days	# Encounters	Distance Surveyed (km)
2017	66	38	4766
2018	64	44	5847
2019	65	46	3001
2020	62	43	5572
2021	53	42	4851
TOTAL	**310**	**213**	**24,037**

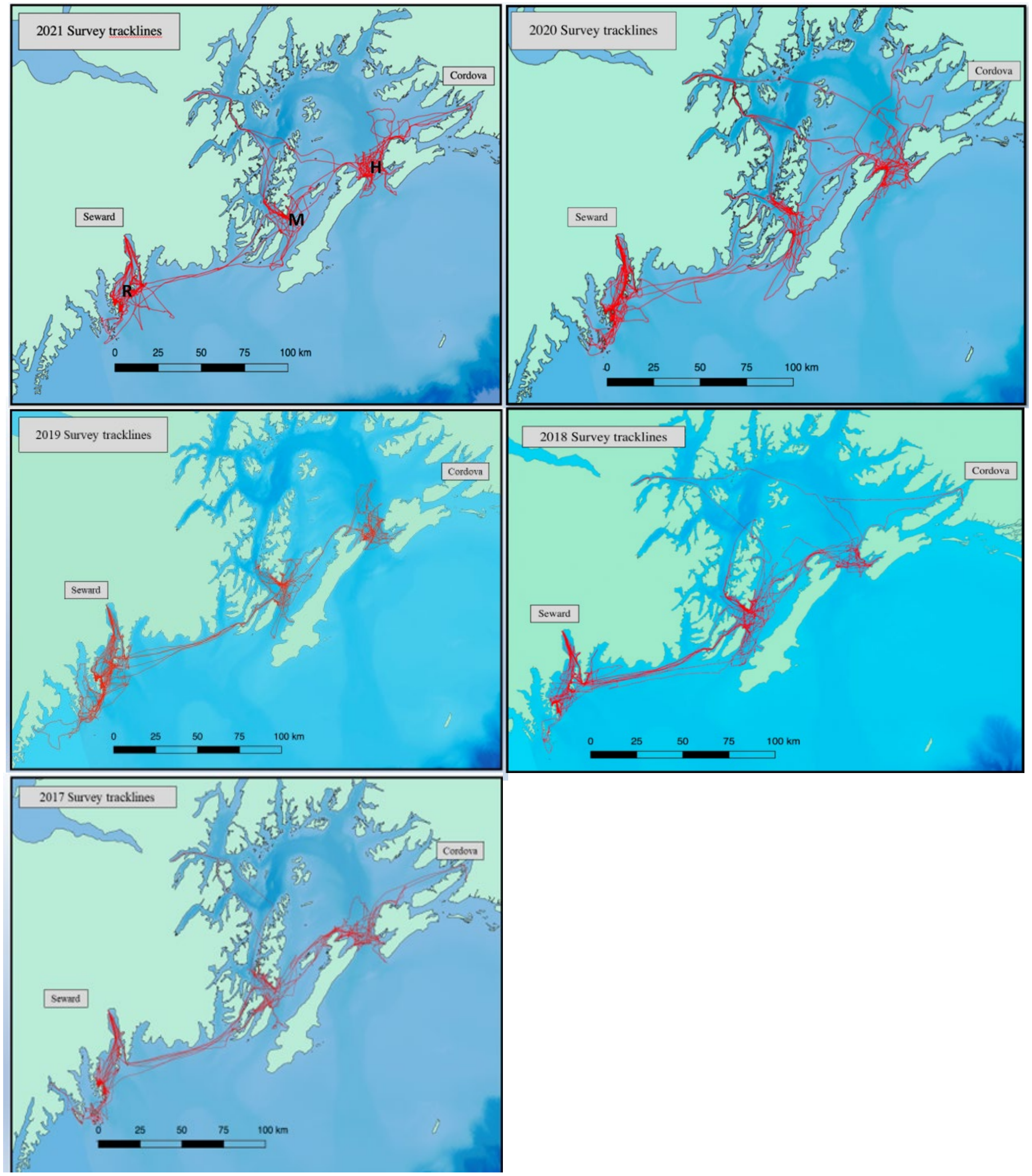

Figure 1. Killer whale survey track lines of the vessel R/V Natoa in Prince William Sound and Kenai Fjords, Alaska, 2017-2021. Surveys were focused in Resurrection Bay (R) in Kenai Fjords, and in two entrances to Prince William Sound: Hinchinbrook Entrance (H) and Montague Strait (M).

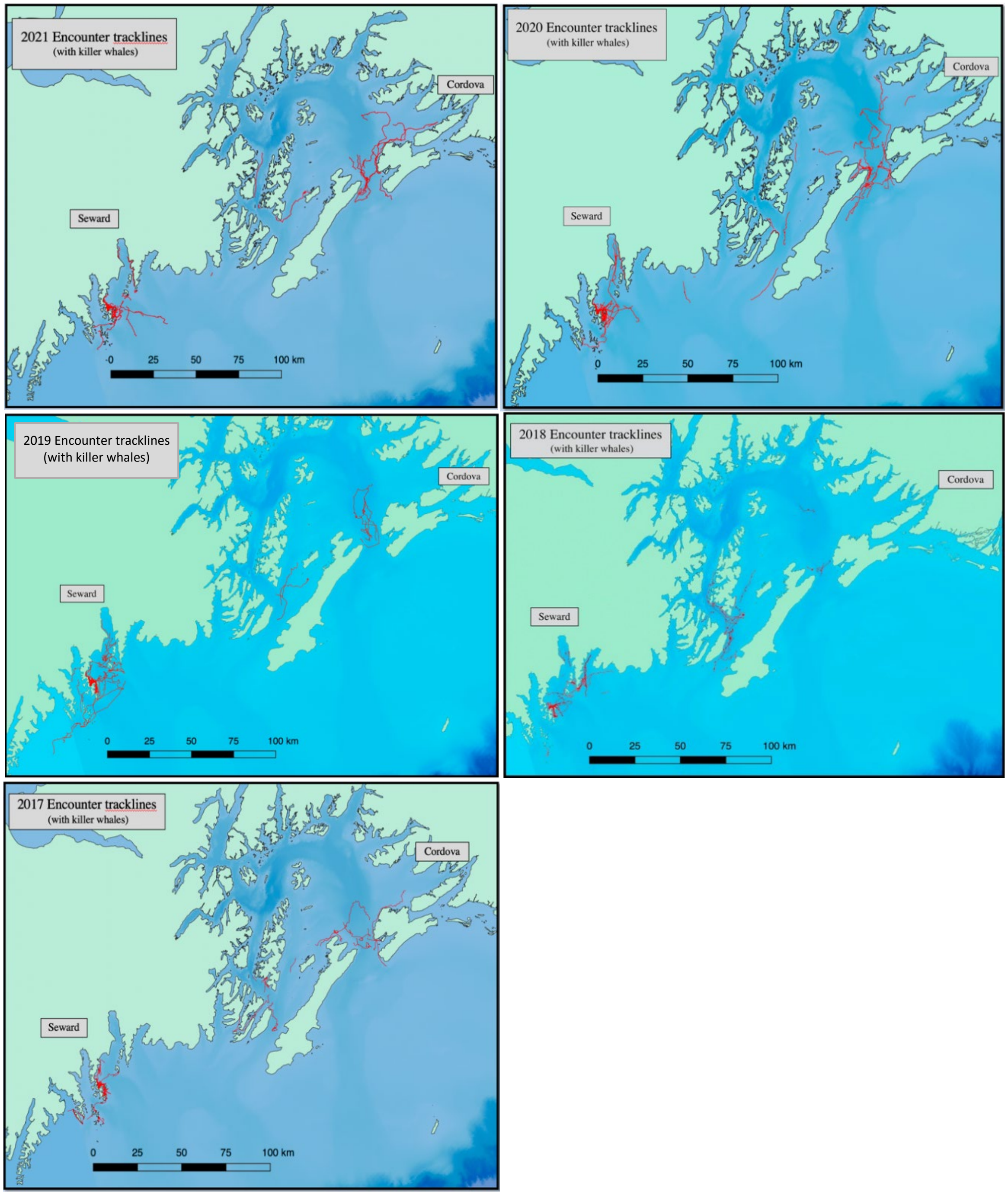

Figure 2. Track lines of encounters with Killer whales from the R/V Natoa in Prince William Sound and Kenai Fjords, Alaska, 2017-2021.

Population trends

Two groups of killer whales are of strategic interest because they are known to have been directly injured by the *Exxon Valdez* oil spill (Matkin et al. 2008): the AT1 population of transients and the AB pod of residents. Neither have yet to recover to their pre-spill numbers

(Fig. 3). During this reporting period, the AT1 population has remained constant at seven individuals, with no mortality or recruitment (Fig. 3). This remains below their pre-spill high of 22 individuals. Further recruitment is not expected because the remaining females are beyond known reproductive age for killer whales. After declining from 26 to 16 whales following the oil spill, AB pod had been slowly recovering to a post-spill high of 22 whales in 2015. However, AB pod declined in this reporting period from 22 whales in 2015 to just 14 whales in 2017, increasing to 16 in 2021. This latest decline came at the end of a marine heatwave during 2014-2016 that has had acute and prolonged impacts on the Gulf of Alaska ecosystem and apparently erased 30 years of post-spill recovery of AB pod (Fig.3).

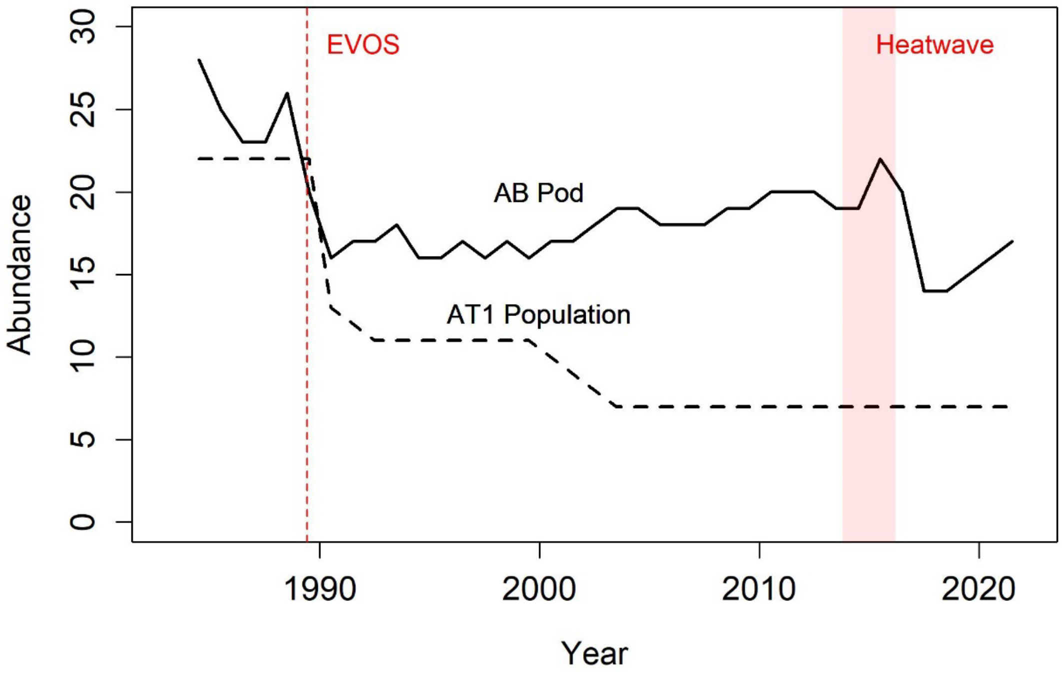

Figure 3. Number of killer whales (Abundance) in the AB pod and AT1 population from 1984 to 2021. The timing of the Exxon Valdez Oil Spill (EVOS) and the Gulf of Alaska marine heatwave are indicated in red.

To provide a comparative context for assessing recovery of AB pod during the 2017-2021 study period, we also monitor other pods within the southern Alaska resident population. We photographed 1060 individual whales in this population but could only monitor the dynamics of regularly seen “index pods” that were encountered and censused annually. In AB clan of acoustically related pods (Yurk et al. 2002), of which AB pod is part, 2 of 5 index pods increased in abundance over the reporting period (AB25 and AI pods). But in total, the number of individuals combined in the AB index pods declined by 2% (Table 2). In contrast 4 of 5 index pods in the AD clan increased in abundance (AE pod was the only exception). In total the number of individuals combined in the AD index pods increased by 18%.

Table 2. Recruitment, mortalities, and total number of killer whales in the five reporting years since 2016 for frequently seen resident pods. Shading indicates pods from the "AB" acoustic clan (see Yurk et al. 2002), listed above those pods from the "AD" acoustic clan.*

POD	Total 2016	Total Recruited since 2016	Total Died since 2016	Year of last census	Most Recent Total
AB	20	3	6	2021	17
AB25	25	4	2	2021	27
AJ	44	4	4	2021	44
AJ08	22	0	3	2021	19
AI	8	2	0	2021	10
AB Clan sum	**119**	**13**	**15**	**2021**	**117**
AE	19	3	4	2021	18
AK02	15	5	0	2021	20
AK06	8	3	1	2021	10
AD08**	8	2	0	2021	10
AD16**	11	3	0	2021	14
AD Clan Sum	**61**	**16**	**5**	**2021**	**72**

**defined as pods that were censused each year during the reporting period*
***these matrilines separated from AD05 pod, as AD05 matriline was not seen during reporting period*

Notably, the 2017-2021 reporting period came immediately after an intense marine heatwave in the Gulf of Alaska between 2014 and 2016 and declines in 4 of 5 AB clan pods (AJ, AJ08, AB, and AI) all occurred at the end of the heatwave (Fig. 4). These impacts were apparently prolonged, as only AI pod had recovered to pre-heatwave numbers by 2021. In contrast all 5 index pods from AD clan continued to increase in abundance through the heatwave years and into this reporting period, although AE pod has subsequently declined. This prolonged disruption to AB clan pods demonstrates the need for continued monitoring to understand how environmental variation has and will affect recovery potential. The contrasting dynamics of different pods within the AB and AD clans of resident killer whales indicates key ecological differences. Investigations of differences in diet, distribution and nutritional health will help understand the factors underpinning these contrasting dynamics.

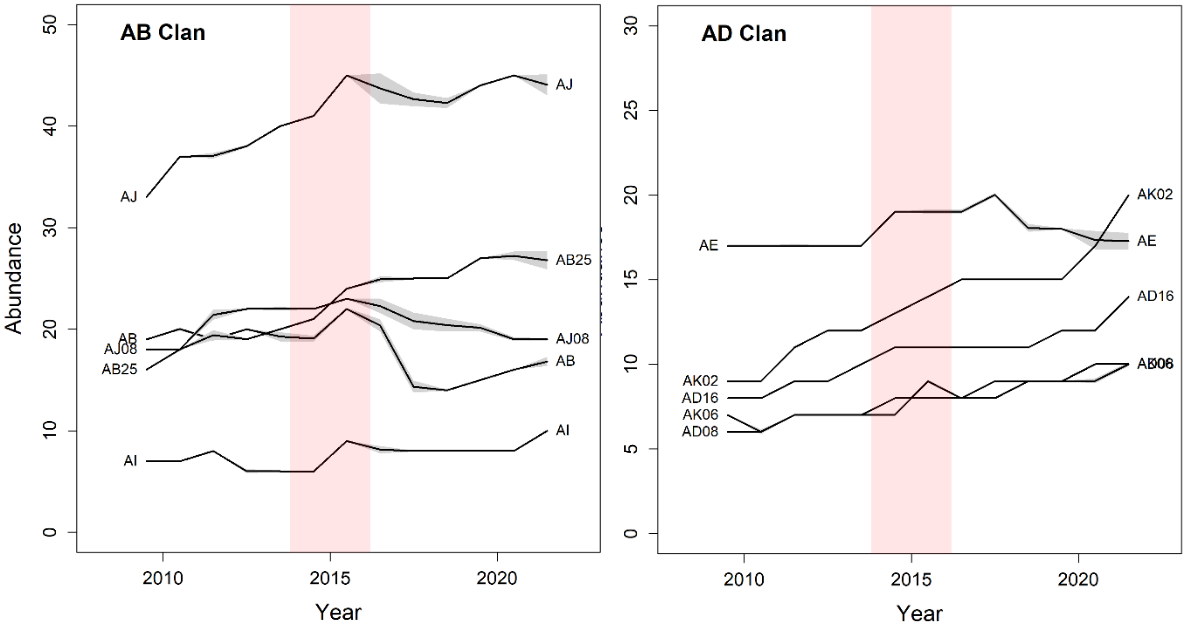

Figure 4. Number of killer whale individuals (Abundance) in each of 10 index pods that were photo-identified annually during the 2017-2021 reporting period. The abundance of each pod is presented for the extended period 2009-2021, representing five years before and five years after the 2014-2016 marine heatwave in the Gulf of Alaska, which is referenced by pink vertical shading. The latter five years represent the current 2017-2021 reporting period. Black lines represent the most likely estimate and gray error bars the standard deviation of estimates from a latent-state mark-recapture model (Ward et al. 2016), which allowed for uncertain birth/death status of some individuals where applicable. These included five pods from each of the AB and AD acoustic clans; pods are labelled at the start and end of abundance trajectories.

Diet

In total, 362 scale/flesh samples from at least 16 pods and 86 fecal samples from at least 8 pods were collected and analyzed for prey species identification. This was reduced 245 and 74 scale/flesh and fecal samples, respectively, when collections within an hour of a previous collection were removed to avoid overrepresentation by individual diet samples (Table 3). The scale/flesh dataset was comprised of samples collected in two geographic regions, Prince William Sound and Kenai Fjords, between May and September, 1991-2021. Most samples (n=138) came from Kenai Fjords early season (May-June), 29 from Prince William Sound early (June-July), 78 from Prince William Sound and Kenai Fjords combined for late season (August-September).

Killer whale fecal samples were collected in the same two geographic regions (Prince William Sound and Kenai Fjords) between May and September, 2016-2021 (Table 3). Most samples (n = 54) were collected in Kenai Fjords early season, while 10 were collected in Prince William Sound early season and 10 in Prince William Sound and Kenai Fiords combined in the late season. Late season Prince William Sound and Kenai Fjords were combined during fecal analysis due to lower sample sizes.

Chum (*Oncorhynchus keta*) and Chinook (*O. tshawytscha*) salmon were the dominant prey species identified from fecal samples in both regions (Table 3). Pacific halibut (*Hippoglossus stenolepis*), arrowtooth flounder (*Atheresthes stomias)* and Coho salmon (*O. kisutch*) and sablefish (*Anoplopoma fimbria*) were also present, in addition to lower occurrence of sockeye salmon (*O. nerka*). These species were the "major prey species" in the fecal dataset, defined as species detected in proportions >1% in at least 4 samples. In the scale/flesh dataset, only chum, Chinook, coho, and sockeye occurred at these levels (Fig. 5). No detection greater than 0.2% was found in any fecal sample for Pacific herring (*Clupea harengus)*, pink salmon (*O. gorbuscha*), or steelhead (*O. mykiss*), and only one herring scale was found in the 245 scale/flesh samples, likely as secondary prey.

Three species were detected in proportions >1% in fewer than four fecal samples: prowfish (*Zaprora silenus*), snailfish (*Liparis sp.*), and eulachon (*Thaleichthys pacificus*). Lumpfish (*Eumicrotremus orbis*) represented 30% of the genetic sequences generated from one fecal sample. Prowfish were detected in three samples collected in Kenai Fjords during the month of June at very low percentages of generated sequences (average of 2.1% of reads per sample) Similarly, snailfish made up 3.3% of reads in one sample collected in Prince William Sound in September, and eulachon made up 1.1% of reads in one sample collected in Kenai Fjords in May. Given the small proportion of each of these species across the genetic sequences generated in a given sample, these species were determined to most likely represent secondary prey items, smaller forage fish consumed by killer whale prey before consumption by killer whale.

Fecal samples, averaged across three spatiotemporal strata had chum salmon proportions (39%) that were slightly higher than Chinook salmon (34.5%). Halibut, arrowtooth flounder and coho were considerably lower at 8.9%, 7.9%, and 7.1% respectively, followed by much lower levels of sablefish (1.4%) and sockeye salmon (0.1%). Scale and flesh samples, averaged across temporal strata, showed congruence with the fecal dataset in high occurrence of Chinook salmon (38.7%) and chum salmon (32.5%), but also showed greater occurrence of coho salmon (27.4%, Table 3). Sockeye salmon was detected in small amounts. Halibut, arrowtooth flounder, and sablefish were not detected in the scale and flesh data, nor was it expected, due to the likelihood of being consumed at depth.

Table 3. Diet diversity for Southern Alaska resident killer whales using scale/flesh sampling of prey (1991-2021) and fecal samples from the killer whales (2016-2021). Data were categorized by location (Prince William Sound [PWS] and Kenai Fjords [KF]) and season (KF early, May 15-June 15; PWS early, June-July; PWS and KF late = August and September) and shown as frequency of occurrence (percent of samples with each prey species). Since fecal samples have multiple species in each sample, we also show the "composition" reflecting the percent of all identified species that a given species represents.

	Chinook salmon	**Chum salmon**	**Coho salmon**	**Halibut**	**Arrowtooth Flounder**	**Sockeye salmon**	**Sablefish**	**Total**
PWS early								
Fecal (n=10)								
Composition	4.1%	70.3%	1.9%	5.6%	15.8%	0.0%	2.7%	99.1%
Occurrence	27.3%	30.3%	6.1%	18.2%	6.1%	0.0%	12.1%	100.0%
Scales/Flesh (n= 29)	20.7%	65.5%	10.3%	0.0%	0.0%	3.4%	0.0%	100.0%
KF early								
Fecal (n=54)								
Composition	68.6%	28.0%	0.0%	2.8%	0.1%	0.2%	0.02%	99.7%
Occurrence	33.3%	25.9%	0.6%	24.7%	13.6%	0.6%	1.2%	100.0%
Scales/Flesh (n= 138)	81.2%	15.2%	0.0%	0.0%	0.0%	2.9%	0.0%	100.0%
PWS, KF late								
Fecal (n= 10)								
Composition	30.9%	18.7%	19.3%	18.3%	7.7%	0.0%	1.4%	96.3%
Occurrence	22.7%	15.9%	6.8%	20.5%	15.9%	0.0%	11.4%	93.2%
Scales/Flesh (n= 78)	14.1%	16.7%	69.2%	0.0%	0.0%	0.0%	0.0%	100%
Mean								
Fecal samples								
Composition	34.5%	39.0%	7.1%	8.9%	7.9%	0.1%	1.4%	98.9%
Occurence	27.8%	24.0%	6.8%	21.1%	11.8%	0.2%	8.2%	100.0%
Scales/Flesh	38.7%	32.5%	27.4%	0.0%	0.0%	1.0%	0.0%	99.6%

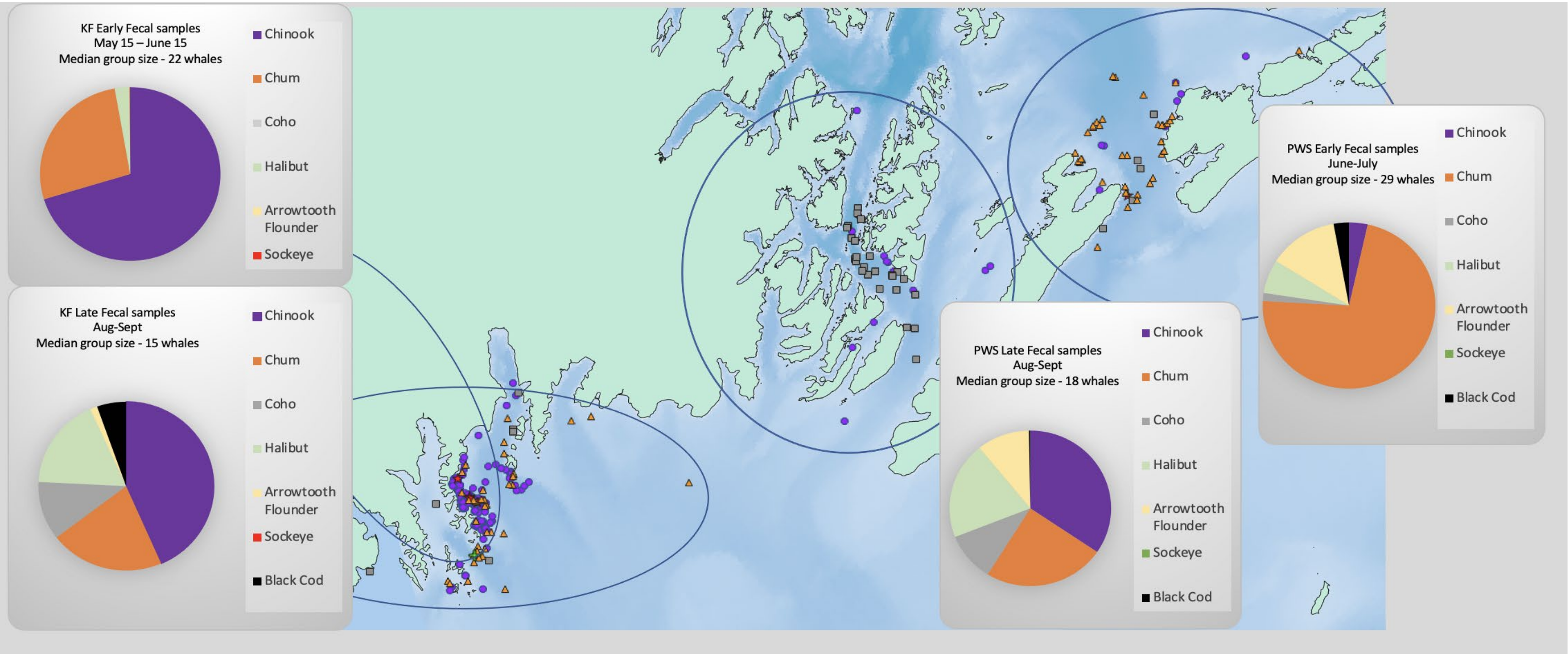

Figure 5. Locations mapped of scales/flesh from predation events (1991-2021; purple circles = Chinook salmon, orange triangles = chum salmon, silver squares = coho, red stars = sockeye salmon, green plus sign= herring). Pie charts show species fecal content of samples (2016-2021) collected in circled locations in Kenai Fjords (KF) and Prince William Sound (PWS) and during indicated time periods.

Fecal sample proportional composition varied significantly between the two regions in the study (PERMANOVA $R^2 = 0.17$, p-value = 0.001), as well as between early and late seasons (PERMANOVA $R^2 = 0.06$, p-value = 0.01). Within Prince William Sound, fecal sample proportional composition varied significantly between early and late seasons (PERMANOVA $R^2 = 0.25$, p-value = 0.02). The alpha value used to determine significance was $p < 0.05$.

Strong differences were noted in the seasonal and regional diet compositions. In the early season, chum salmon was the dominant prey item (70.3%) in Prince William Sound whereas in Kenai Fjords, Chinook salmon was dominant (68.6%). Coho was present in Prince William Sound early, but increased in late season in Prince William Sound, more strongly in the scale/flesh data.

Halibut represented greater than 5% of the prey sequences generated from individual fecal samples during all months except one (August, >1%), was detected in both regions, and represented over 20% of the prey composition in fecal samples collected from AE and AK pods. Arrowtooth flounder was detected in fecal samples from both AE and AJ pods in all months sampled. Sablefish was detected as a primary prey item (> 1% prey sequences) in a small number of samples in June, August, and September, in both regions.

Diversity indices within the fecal dataset differed between the seasons and regions, and were generally higher late season than early season, and higher in early Prince William Sound than in early Kenai Fjords (Fig. 5). Prey species diversity (estimated as the number of prey species representing >1% of prey sequences was lowest (mean 1.64 species per sample) in Kenai Fjords early, mean 2.15 for Prince William Sound early, and highest (mean 3.00 species per sample) for late season combined regions.

One instance of sampling feces from mother and offspring occurred on May 29, 2018. The prey genetic composition of fecal samples for AD031 and her male offspring AD054 contained the same 4 species in very similar proportions 81% and 77% chum, 9% and 19% Chinook, 9% and 4% halibut, and <1% each arrowtooth flounder.

Interannual effects were difficult to assess in this study, due to limited sample size within years. However, sufficient feces were collected in early season Kenai Fjords to demonstrate a notable difference during 2018 (chum 78%, Chinook 20%, n=15) from other years which were dominated by Chinook salmon.

These results show a salmon dominated diet with the specific salmon species varying by season and region. However, non-salmonids specifically include halibut, arrowtooth Flounder and sablefish were also present in the diet. Our sampling occurred during spring and summer, but not fall and winter, which are difficult to sample. Winter and offseason sampling will be important for accurate ecosystem modeling.

Habitat use

For a detailed summary of killer whale habitat use and distribution, see Appendix 1: Myer et al. 2021. "Passive acoustic monitoring of killer whales (*Orcinus orca*) reveals year-round distribution and residency patterns in the Gulf of Alaska".

Photogrammetry

We recognized the need to better understand nutritional health and the ecological factors underpinning the contrasting pod-specific population dynamics. Towards this objective (#6) we tested drones for photogrammetry measurements of health metrics. We successfully flew 20 drone flights over three days in late May 2021 and two drone flights on one day in August 2021. In total, we collected 17,822 aerial images. We encountered two pods of resident killer whales and were able to compile aerial catalog images to distinguish all members of the AK02 and AD08 pods (30 individuals total) based on the appearance of pigmentation and scratches on their saddle patches from the air (Fig. 6). This included whales of all age and sex classes, ranging from four calves of the year (AK38, 39, 40 and 41; Fig. 7) to an adult female of at least 40 years old (AD8) and an adult male of 28 years (AD22). Members of the AK02 pod were imaged in both May and September, demonstrating our ability to match aerial images and develop longitudinal data of measurements of the same whales (Fig. 6). Multiple images were collected for each individual, which will allow measurements of the whale in the "flattest" surfacing orientation (body parallel to the water's surface) to be selected to minimize bias. For example, individuals in AD08 pod (analyses for AK02 pod still underway) were represented in a median of 34 measurement-quality images (range 9-70).

Following the successful feasibility test in 2021, drone-based photogrammetry was added to our research for 2022 and we are growing our database of aerial images. This database will be used to quantify length-at-age relationships to examine growth, and to measure body condition to infer nutritional health and pregnancies. These metrics will be used in analyses to compare the condition and size of different pods, to evaluate the influence of female size on reproductive success and to track temporal changes in growth and body condition in response to environmental change. Additionally, we aim to compare the body condition and size of Alaska resident killer whales to other killer whale populations, specifically the endangered Southern Resident killer whales off Washington State to allow regular comparison of the general nutritional health between populations.

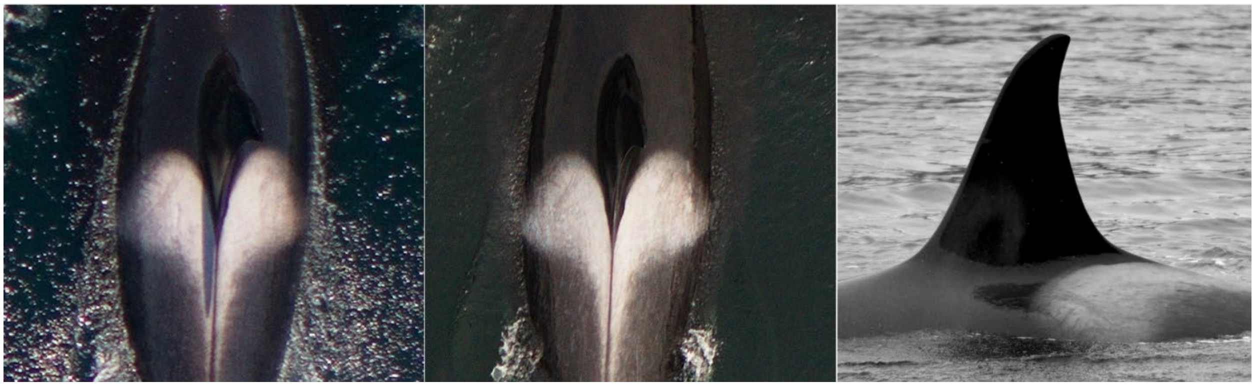

Figure 6. Whales imaged by drone can be matched to our long-term photo-identification catalog using natural markings on their saddle patches. See the scars on the left side of AK9's saddle, visible from both the aerial (left and middle, on two different days) and boat-based images (right). This allows measurements of morphology to be linked to whales of known age, sex and pod affiliation. We are using aerial images to measure length, body condition and pregnancy stats. These are sensitive indicators of individual health and, in combination, population status.

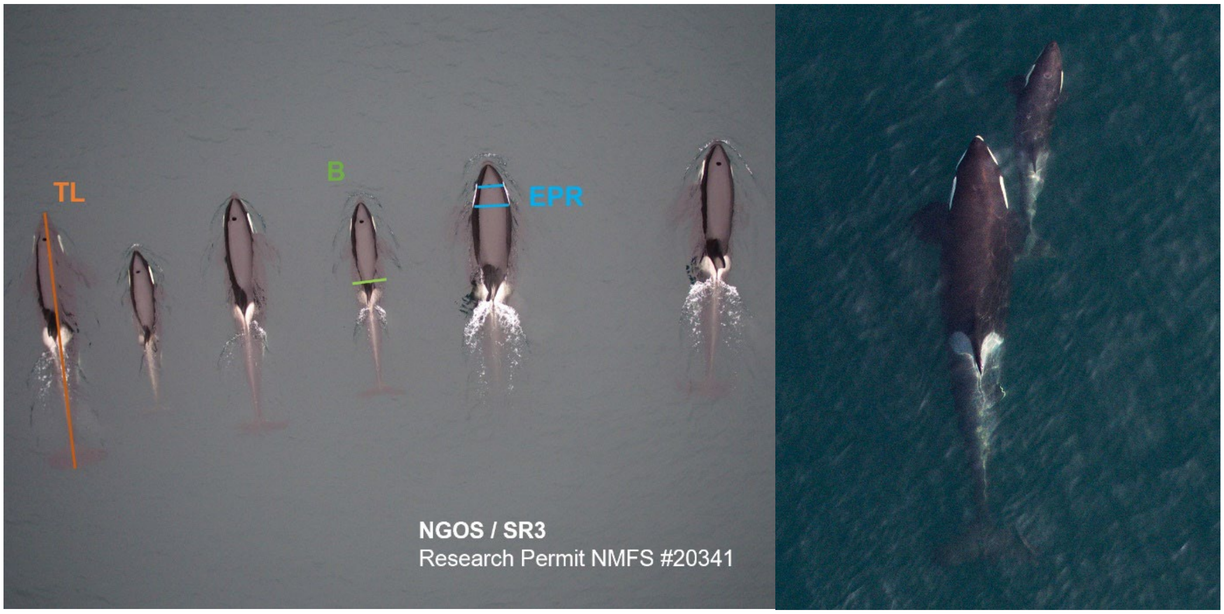

Figure 7. Left) Aerial image of part of the AD08 pod off Kenai Fjords, Alaska, in late May 2021. Annotations show photogrammetry measurements of total length (TL), breadth (B) used to infer pregnancy of females and the eye patch ratio (EPR) indicating body condition by measuring divergence of the eye patches with increased fat deposits behind the head. Right) Aerial image of a calf (AK42) from the AK02 pod in its first year of life, and its mother (AK17). Lactation to support dependent calves is energetically expensive, so monitoring the condition of adult females and the growth of their calves can provide sensitive insight into nutritional health. Image taken from >100 ft with a remotely controlled octocopter drone under NMFS research permit #20341.

DISCUSSION

Although the *Exxon Valdez* Oil Spill Trustee Council has shown reluctance to continue funding of the killer whale monitoring program, the two groups of killer whales remain of strategic interest because they are known to have been directly injured by the *Exxon Valdez* oil spill (Matkin et al. 2008). Neither has fully recovered and one that was increasing since the spill (the resident AB pod) declined during this reporting period. The resident AB pod, the most frequently sighted pod prior to the spill, declined to a low of 14 whales in 2017 and currently numbers only 17 compared to 26 the year before the spill. Prior to the 2014-2016 marine heatwave, the resident AB pod had been trending upwards for 26 years, reaching 22 whales in 2016, only 4 individuals less than pre-spill levels. The AT1 transient population has not produced a calf in almost three decades and appears headed to extinction. It numbered 22 whales prior to the spill and now contains only 7 whales.

The AB pod and other resident pods experienced abrupt declines in abundance at the start of this reporting period, likely in response to a marine heatwave that impacted the entire marine ecosystem in the Gulf of Alaska (Suryan et al. 2021) and may be a harbinger of the future as the oceans continue to warm. Notably, the 2017-2021 reporting period followed the intense 2014-2016 marine heatwave, following which four out of five AB clan pods (AJ, AJ08, AB, AI) all declined. These impacts were apparently prolonged, as only AI pod had recovered to pre-heatwave numbers by 2021. In contrast all 5 index pods from AD clan continued to increase in abundance through the heatwave years and into this reporting period, although AE pod has subsequently declined. The different population responses raise questions about the pods varying abilities to respond to environmental change.

We have reported new data that describes a diverse diet for southern Alaska resident killer whales, departing from the simplistic hypothesis of an overwhelming preference for Chinook salmon for the resident ecotype of killer whales in the North Pacific (Ohlberger et al. 2018). Our results show a summer diet dominated by salmon, including Chinook, chum and coho salmon with the specific salmon species of preference varying by season and location. Non-salmonids, specifically includes halibut, arrowtooth Flounder and sablefish were also present in the diet. This evidence for diversity builds on previous diet studies that have shown salmon species in addition to Chinook to be important in some locations and times, including coho and chum in summertime diet for resident killer whales off Russia (Volkova et al. 2019) and coho and chum salmon increasing in importance in the fall diet of southern resident killer whales off Washington State (Hanson et al. 2021). Continued diet monitoring is necessary to understand the impact of changes in prey abundance, especially the ecologically and economically important salmon, on the whales.

Our data provided a preliminary indication that diet varies between specific resident pods, which highlights the importance of sampling multiple pods in future studies of feedings. For example, arrowtooth flounder in our samples was primarily attributed to AE pod, which comparatively has a very small range (Olsen et al. 2018). Stable isotope values for tissue samples for this pod were higher for other pods (unpublished data), and a higher dependence on large flatfish could explain this difference. Interestingly, calf productivity and adult survival rates for this pod were lower than for other pods in the AD Clan (Durban, pers. com). Continued diet sampling is necessary to fully understand the link between population dynamics and dietary variation between pods of resident killer whales.

For a detailed discussion of killer whale habitat use and distribution, see Appendix 1: Myer et al. 2021. “Passive acoustic monitoring of killer whales (*Orcinus orca*) reveals year-round distribution and residency patterns in the Gulf of Alaska”.

This long-term monitoring project is a unique opportunity to continue a comprehensive database initiated in the early 1980s for one of the regions sentinel marine species. The importance of long-term killer whale monitoring has been borne out by companion studies in other regions such as the Salish Sea waters off Washington State and around Vancouver Island, British Columbia. This project has benefited from continued support of the *Exxon Valdez* Oil Spill Trustee Council and from individuals living in coastal communities along the north Gulf coast of Alaska. Killer whales are also a primary focus of viewing in the region by a vibrant tour boat industry. Data from this project are used by tour boats in several Alaskan communities to enhance viewer’s experience and to promote appreciation of the local environment and fauna.

CONCLUSIONS

The prolonged disruption to AB pod, and other AB clan pods, following the 2014-2016 marine heatwave has demonstrated the need for continued monitoring to understand how environmental variation has and will affect recovery potential. AB pod increased post-spill until this heatwave, then declined during this study period and was still far below pre spill numbers. The AT1 population did not decline, but numbers only 7 whales and appears headed for extinction.

Our findings indicate a dietary preference by Southern Alaska resident killer whales for chum, Chinook and coho salmon during May to September, but diet also includes halibut, arrowtooth flounder and sablefish. Diet differed between regions and seasons and there was an indication of pod-specific differences. As the sample size builds, it will be important to investigate pod- and clan-specific dietary differences to understand ecosystem interactions underpinning their population dynamics.

Remote acoustic monitoring was found to be a viable year-round method of monitoring killer whale abundance and distribution in high-use areas. All ecotypes (resident, transient, offshore), populations and pods can be monitored due to unique vocal dialects.

Drone photogrammetry was found to be a viable method for quantifying nutritional health. We plan to use this method routinely alongside our vessel-based photo-identification to monitor temporal changes in growth and body condition in response to environmental change.

ACKNOWLEDGEMENTS

The North Gulf Oceanic Society would like to thank the many supporters and donors who also contribute to the continuation of this long-term study. NOAA Fisheries' Northwest Fisheries Science Center, specifically Drs. Kim Parsons and Amy van Cise provided invaluable analytical support diet studies using fecal DNA, and in describing their methods for this report. Department of Fisheries and Oceans' Pacific Biological Station, specifically Brianna Wright, analyzed scale and tissue samples for the feeding habits studies. This project is part of the Gulf Watch Alaska Long-Term Research and Monitoring Program. These findings and conclusions presented by the author(s) are their own and do not necessarily reflect the views or position of the *Exxon Valdez* Oil Spill Trustee Council.

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APPENDIX 1

See separate PDF.